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Operational Performance of the Photovoltaic-Powered Grain Mill and Water Pump at Tangaye, Upper Volta

James E. Martz, Anthony F. Ratajczak,
and Richard DeLombard
*Lewis Research Center
Cleveland, Ohio*

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OPERATIONAL PERFORMANCE OF THE PHOTOVOLTAIC-POWERED GRAIN MILL
AND WATER PUMP AT TANGAYE, UPPER VOLTA

by James E. Martz, Anthony F. Ratajczak and Richard DeLombard

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

INTRODUCTION

As part of a project sponsored by the U.S. Agency for International Development (AID) entitled "Studies of Energy Needs in the Food System," a photovoltaic (PV) system powering a grain mill and water pump was installed in the remote African village of Tangaye, Upper Volta by the NASA Lewis Research Center (LeRC).

Tangaye is a village of about 2900 located 190 km east of Ouagadougou, the capital of Upper Volta. The main occupations of its inhabitants are farming and cattle raising. The PV system was initially sized to both pump water from the village well and (due to funding limitations) meet a portion of the village's grain grinding needs. Accordingly, the system consisted of a 1.8 kW peak 120 volt DC PV array, 540 ampere-hours of battery storage, and controls and instrumentation designed by LeRC.

The system became operational on March 1, 1979. From a technical standpoint, the project was intended by AID to demonstrate that PV systems could provide reliable electrical power for multiple-use applications in remote areas where local technical expertise was limited. As of April 1981, the water pump and grain grinder had been operational 97% and 90% of the time, respectively. Because of the success of the project, the Government of Upper Volta requested that the system be doubled in electrical capacity. This was accomplished by NASA Lewis personnel with the assistance of the village residents in May of 1981. This expansion represents the first instance of a PV system being scaled up by a factor of two in a field operational setting.

This report summarizes the first two years of system operation covering the period March 1979 to April 1981.

SYSTEM DESCRIPTION

General

The Tangaye PV system consists of a PV array, batteries, controls and instrumentation. The PV system powers a hammermill for grinding grain, a water pump which provides both domestic and stock water, and lights in the mill building.

The system was sized to provide approximately 5000 liters of water per day (the measured recovery rate of the well) estimated to serve up to 500 people in the dry season, and approximately 320 kilograms of cereal grain per day, estimated to serve approximately 640 people.

The people of the village organized a cooperative (Groupment) to manage the operation of the mill. The cooperative is responsible for selecting and hiring milling personnel, determining milling prices and operating hours, and managing the funds collected for the milling. No charge is made for use of the water system. The water is freely available to all villagers.

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The PV array is located in a fenced area, about 10 meters NE of the well. Power is distributed by means of underground wires to a mill building located about 5 meters NW of the well. The mill building consists of two rooms; one contains the mill, controls and instrumentation while the other contains the batteries. There are two 20 watt fluorescent lamps in the milling room. The water pump is mounted on the concrete casing of an existing 10.4 meter deep by 1.8 meter diameter well. The pump discharge is piped into a 6 cubic meter water storage tank. The storage tank, located 6.4 meters SW of the well, is a horizontal cylinder 1.59 meter in diameter and 3 meters long and is mounted on a metal stand approximately 1 meter above grade with the feet resting on concrete footers. The tank is filled through a manhole in the top and the water is dispensed through a manifold and 5 spring-loaded faucets located along the bottom side of the tank. A catch basin and drain under the faucets carries waste water away from the tank area.

A block diagram of the system is shown in Figure 1 and pictures showing various aspects of the system are shown in Figure 2. Additional general information relative to the system as well as the overall project is given in references 1 through 3.

PV System Design Description

PV array and battery sizes were determined using a NASA LeRC-developed computerized PV system simulation program. The program combines PV cell characteristics, average monthly insolation and atmospheric data, and an hourly load profile to determine hourly battery depth-of-discharge (DOD) as a function of array size, tilt angle and battery capacity. It also incorporates a factor for module output losses due to dirt and encapsulant darkening, and a subroutine to randomly vary insolation within selected limits to develop worst-case DOD conditions. Simulation computations indicated that battery maximum DOD under normal operating conditions would be 30%.

The PV array, battery and loads operate at 120 volts DC. Controls and instrumentation operate at 12 V DC. Use of DC systems avoids the costs, complexities, and losses associated with DC-AC inverters while 120 volts minimizes line losses and permits the use of commercially available DC switches and motors.

All electrical load devices were individually selected on the basis of energy efficiency and reliability. Permanent magnet motors were chosen because of their high efficiency (about 85%). The lights employ commercially available high efficiency 120 V DC, 23 kilohertz inverter ballasts which enable a standard 20 W lamp to produce about the same lumen output as a 75 W incandescent lamp.

The PV system design and installation conforms to National Electrical Codes and OSHA safety regulations and specifications. Additional safety features are a 1.2m high chain-link fence with a locked gate surrounding the array field, warning signs, and an enclosed pump assembly.

PV Arrays - There are two PV arrays in this system, a 120 volt array for all load components and a 12 volt array for the instruments and controls.

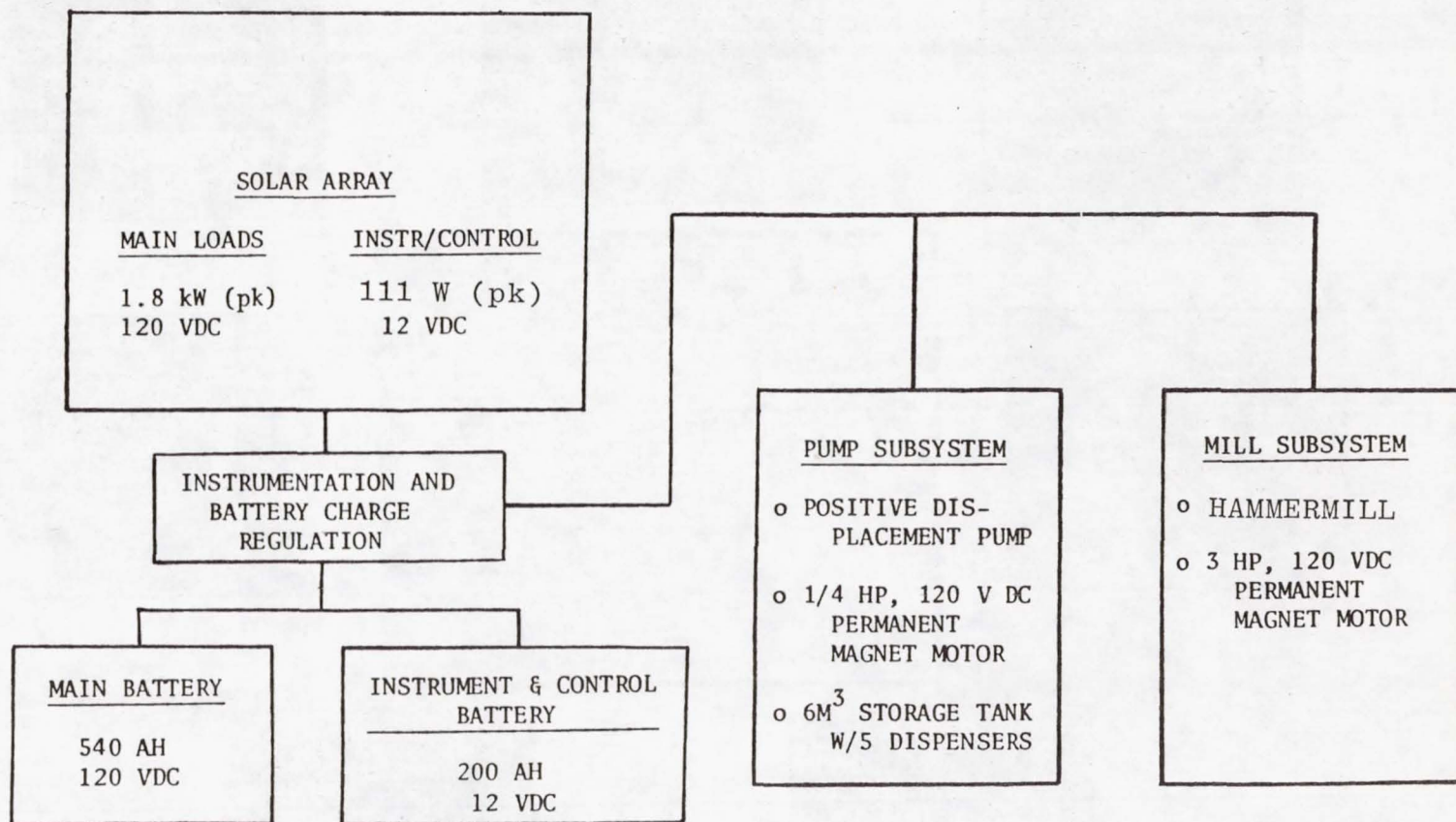
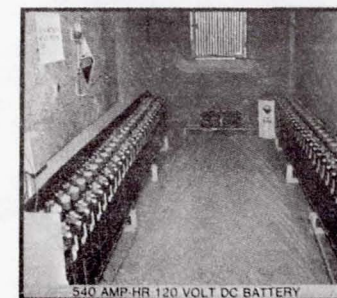
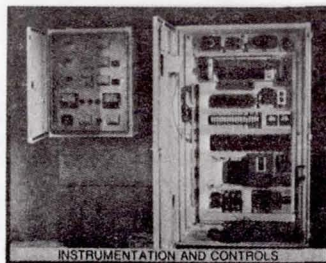
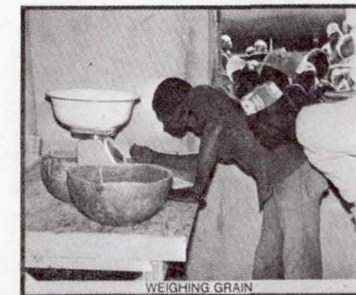
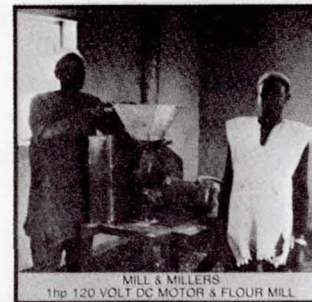


FIGURE 1 - SYSTEM DIAGRAM: PHOTOVOLTAIC-POWERED PUMPING/MILLING SYSTEM,
TANGAYE, UPPER VOLTA



TANGAYE VILLAGE SOLAR ELECTRIC SYSTEM

FIGURE 2.

The 1.8 kW peak, 120 volt PV array consists of 12 series strings of 8 modules each. The modules are assembled into twelve 1.22m by 2.44m panels each containing 8 modules wired as 1 series string. The panels are arranged in 3 rows of 4 panels each. Array tilt angle is fixed at 11° from the horizontal.

A 111 W peak 12 volt array provides power for instruments and controls. This array contains one panel of 6 modules, each module having its own voltage regulator, one with all modules connected in parallel. The 12 volt array panel is located at the west end of the front panel row in the array field.

Batteries - There are two battery subsystems; a 120 volt battery for the loads and a 12 volt battery for instruments and controls. The 120 volt battery consists of fifty five 540 ampere-hour cells (nominally 2 volts each) designed specifically for PV system operation. The battery cells are mounted on two single-tier racks located in a separate vented room of the mill building.

The instrument and control battery consists of two 6 volt 200 ampere-hour industrial batteries connected in series. Battery cells designed for PV system operation were originally purchased for the instrument and control subsystem. However, they were damaged in shipment to Upper Volta and could not be used. Industrial batteries were purchased locally and have remained in the system.

Controls - The system has three control subsystems: system voltage regulation and battery charge regulation, over- and under-voltage protection, and pump and mill controls. System voltage regulation and battery charge control are accomplished by array string switching. Two separate voltage control subsystems provide additional system reliability. One system uses an electromechanical device to control voltage and the other is all electronic. The subsystems are independent and selectable by the local operator. Over-voltage controls disconnect the PV array in the event the voltage control subsystem fails, and under-voltage controls disconnect the loads to prevent excessive battery discharge in the event of loss of array power or excessive load use. The pump controls consist of a water level sensor in the water storage tank to stop and start the pump and a water level sensor in the well to stop the pump when the well water level drops below the pump intake. The mill controls consist of interlock switches and an optional timer system to limit daily operating time.

Instrumentation - The system contains instrumentation which indicates instantaneous values of system voltage and array, mill, and pump currents. There are also ampere-hour meters which record cumulative PV array output and load consumption as well as run-time-meters which record the total operating time of the mill and pump motors. Data from these instruments are recorded daily and forwarded to NASA LeRC periodically for reduction and analysis.

Mill - The principal load in terms of power consumption is the flour mill. The Bell #10 hammermill is powered by a Honeywell (Applied Motors) 3 horsepower 120 volt DC permanent magnet motor. The mill is capable of grinding grain with hulls on thus saving women the task of dehulling prior to grinding.

Pump - The water pump is a Jensen Manufacturing Co. model No. 11W5A positive displacement lift pump and is powered by a Honeywell (Applied Motors) 1/4 horsepower 120 volt DC permanent magnet motor. Because pump operation is automatic, the complete pump assembly is enclosed in a metal screen cage to prevent injury to villagers.

INSTALLATION & TRAINING

Installation and training was begun in mid-January 1979 and completed on March 1, 1979. This task required a total of 12 man weeks involving two NASA LeRC engineers and one NASA LeRC technician. AID/UV personnel contracted for local fabrication and installation of the NASA LeRC designed water tank, and arranged for villagers to construct the NASA LeRC designed mill building, all prior to the NASA team's arrival.

System hardware installation was accomplished with considerable assistance from the men of the village as well as AID and Peace Corps personnel. The mill building was constructed by men of the village using locally made mud bricks. Cement, lumber, steel reinforcing rod, and sheet metal roofing were supplied by AID/UV.

Under NASA LeRC supervision, men from the village assembled the PV panel support structures, prepared the footer trenches for the support structures, installed the support structures, mounted the PV array panels, and back-filled the support structure footer trenches. The village men also prepared the trenches for the underground wiring from the PV array to the mill building, from the building to the well, and for the tank switch control wire and water pipe from the well to the tank. The men also helped with numerous other tasks ranging from unloading the trucks to placing the battery cells on the racks in the battery room. To state that village support and assistance was enthusiastic is an understatement.

AID/UV personnel provided logistics support and overall coordination with the village leadership and with the Eastern Office of Rural Development (ORD) of the Government of Upper Volta (GOUV). A Peace Corps worker from the Central ORD who was fluent in French and Mossi (the local dialect) spent considerable official and personal time assisting with installation and training.

Installation proceeded swiftly and smoothly with water pump and mill operation beginning in mid-February. The last week of February was devoted to training the Voltaic assigned to monitor the system and the millers selected by the cooperative to operate the mill.

A three-part operations manual was provided to enable the villagers, GOUV personnel and AID/OUAGA personnel to understand, use, maintain and repair the system. Section 1, the Users Manual, was intended for the villagers. This manual consisted of stylized drawings showing how the complete system operates from sunlight in to flour and water out. A brief text in both English and French accompanied each drawing. Section 2, the operations and maintenance manual, is intended to guide the station keepers⁽¹⁾ in operation and normal

(1) Millers and persons charged with monitoring the PV system operation and performing routine maintenance.

maintenance of the system. Section 3, the Trouble Shooting and Repair section, contains a technical description of system operation, all the drawings, schematics, and wiring diagrams and a troubleshooting guide and repair instructions.

As the final phase of the installation effort, NASA LeRC personnel trained the station keepers and AID/UV personnel in system operation, maintenance, and repair. The training consisted of:

- o PV system safety procedures.
- o A complete description of the system, how it operates, and familiarization with drawings and schematics.
- o Instructions on PV array and battery maintenance (washing the array and adding water to the battery cells).
- o Troubleshooting hypothetical problems and repairing or replacing components in the control system, instrumentation, PV array and battery.
- o Semi-automatic and manual operation of the PV system controls in the event of an automatic controls failure.
- o Routine maintenance of the water pump and storage tank (pump piston and stuffing gland gasket replacement, tank flushing, pump switch repairs). Under NASA LeRC supervision, the station keepers removed, disassembled, reassembled, and re-installed the pump assembly.
- o Operation of the mill including:
 - Safety procedures
 - Daily servicing and cleaning
 - Grain feed rates
 - Grinding fineness adjustment

Following training, NASA LeRC observed village personnel operate the system and grind flour for three days. The station keepers quickly became proficient in mill operation and by the third day were developing grain and flour handling routines to increase their overall efficiency.

OPERATIONS AND DATA

Comments on System Operation

The system has performed reliably and satisfactorily during the first two years of operation. However, there have been two significant problems; one related to the type of mill installed initially, and the other related to the design of the particular PV modules used.

Because of project funding limitations, a burr mill was originally selected for the system. This type of mill is in common use in the area. It is low cost and requires only a 1 horsepower motor. Tests at LeRC had confirmed that it would grind flour of sufficient fineness to meet village demands and the throughput, based on 8 hours/day operation, would make a measurable impact on the lives of some of the village women (Appendix A). Although the mill operated satisfactorily, the wear rate of the burr plates was much greater than anticipated and, in fact, the villagers desire for very fine flour resulted in extremely high wear rates on other parts of the mill as well. Within 3 months after the system became operational, one mill had completely worn out and a replacement was rapidly heading to the same demise.

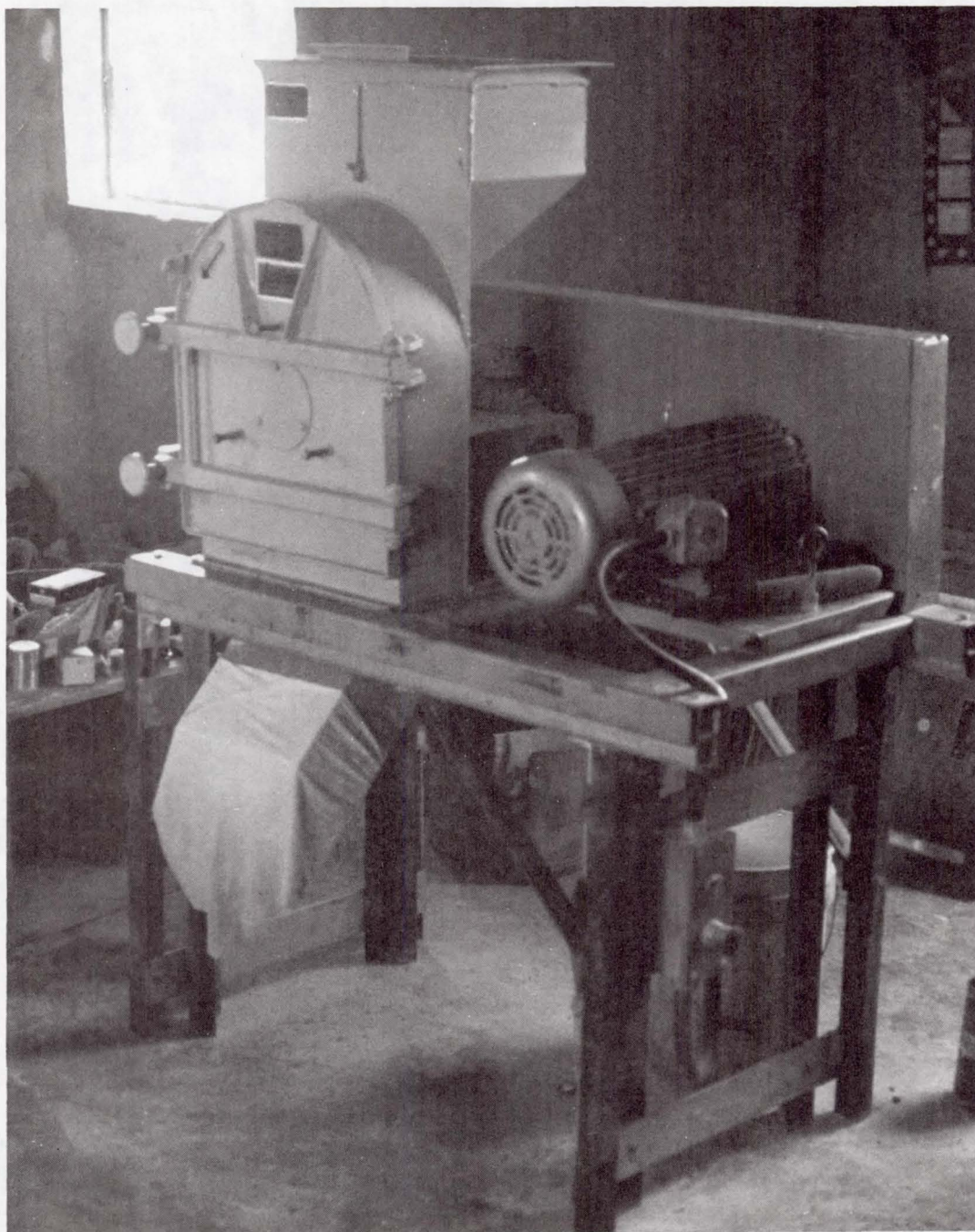
Once the problem became apparent, LeRC personnel procured a C.S. Bell Model 10 hammermill, a 3 horsepower motor and a 2 step motor starter and conducted fineness and throughput tests at LeRC. The cost of the hammermill, motor, and motor starter was approximately \$1,400, or twice that of the burr mill and 1 hp motor. However, the tests indicated that the hammermill could produce flour of sufficient fineness and showed the hammermill to have a throughput (for comparable fineness) ranging from 2 to 5 times that of the burr mill, depending on type of grain being ground and the fineness of the ground product (Appendix B). Additionally, the wear problems associated with the burr mill are absent in a hammermill. However, since this mill with a 3 hp motor requires 3 times as much power as the burr mill, milling time had to be reduced from 56 hours/week to approximately 20 hours/week so as to be compatible with the design energy output of the PV array.

The hammermill and motor were shipped to Upper Volta in July 1979 and installed by LeRC personnel in September 1979 (Figure 3). Except for an initial minor seal erosion problem which allowed some unground grain to enter the flour and which has since been remedied, the mill has performed satisfactorily since its installation. An unexpected benefit of this mill to the women is the fact that it will grind the grain without first removing the hulls. This capability relieves the women of the chore of dehulling the grain which they would otherwise need to do before hand grinding or before milling in the diesel-driven stone (burr type) mills commonly used in Upper Volta.

In August, 1979, upon the recommendation of the International Development and Research Centre of the University of Alberta in Edmonton, Canada, LeRC procured a Jacobson Model 120-B hammermill for evaluation. Fineness and throughput tests conducted at LeRC (Reference 3) indicated that the Jacobson mill would have a throughput for comparable fineness ranging from 2 to 3 times that of the Bell hammermill. In addition, its design should preclude the minor problem of seal erosion experienced with the Bell hammermill. A Jacobson hammermill was shipped to Upper Volta in January of 1981 and installed by LeRC personnel in May, 1981 (Figure 4).



BELL MODEL #10 HAMMERMILL
FIGURE 3



JACOBSON MODEL 120-B HAMMERMILL
FIGURE 4

The other significant problem with the system has been the premature failure of the PV modules. This problem, which results in the module failing open circuit, is the result of a design error and qualification testing oversight. The failure mechanism is common to all modules of similar design made by that manufacturer. This module failure mode was first discovered in the NASA LeRC/DOE village power system at Schuchuli, AZ, which uses the same modules⁽¹⁾. After the problem appeared at Schuchuli in the autumn of 1980, a closer examination of the data from Tangaye revealed the same failure mode there.

Failed modules from Schuchuli were removed and sent to the Jet Propulsion Laboratory - Low Cost Solar Array (JPL-LSA) Project Office⁽²⁾ for failure analysis. That analysis indicated that a significant thermal coefficient of expansion difference exists between the module substrate and the silicon solar cells. This mismatch results in excessive stressing of the cell interconnects with subsequent fatigue and failure (open circuiting) of the interconnects. Approximately 30% of the Schuchuli modules and 29% of the Tangaye modules had failed in this manner by April 1981.

Upon identification of the failure mode, modules obtained under the JPL-LSA project from a different manufacturer and of a different design were evaluated and tested as possible replacements for the original Tangaye modules. These replacement modules were selected on the basis of design, operational history in another LeRC system, and their ability to replace the original modules without major system modifications. A sufficient number of suitable modules were found in the LeRC/DOE inventory to replace the original modules and to double the array size to 3.6 kW peak to increase allowable milling time to the range of 48 to 56 hours per week. These modules were made available to this project by the DOE and were installed in May of 1981 (Figure 5).

Additional minor problems which occurred in the system generally did not require significant system shutdown times and were satisfactorily resolved by local personnel. LeRC personnel provided advice on problem resolution via cable, telephone and letter, and provided additional spare parts when necessary. This method of "long distance" problem resolution has worked satisfactorily and has demonstrated that PV systems can be maintained by local personnel.

System Performance Summary

Overall, the system has operated satisfactorily during the initial two-year period and has been on-line 97% of the time i.e., the load bus has been energized 97% of the time. A summary of the system operating data is presented in Table 1. A typical system daily data sheet as provided by the station keeper is shown in Figure 6.

(1) The Schuchuli village PV power system was installed in the Papago Indian Village of Schuchuli, Arizona in December of 1979. It was funded by DOE and implemented by LeRC. The purpose of the experiment was to demonstrate that a stand-alone PV power system could provide dependable power for basic human needs in a remote village environment.

(2) The JPL-LSA Project Office is part of the U.S. Department of Energy's National Photovoltaic Program.



FIGURE 5. - TANGAYE PV ARRAY
EXPANDED TO 3.6 Kw PK.
MAY 1981

LeRC

TANGAYE DATA
SUMMARY
March 1, 1979 to March 29, 1981

BURR MILL

Total running hours	522 hours
Rated current	7 amps
Actual average current	7.02 amps
Total amp-hrs used	3,665 amp-hrs
Total energy used	440 kilowatt-hrs

HAMMERMILL

Total running hours	1,639 hours
Rated current	21 amps
Actual average current	14.43 amps
Total amp-hrs used	23,649 amp-hrs
Total energy used	2,838 kilowatt-hrs
Total grain ground	48,861 kilograms
Grain grinding rate (Very fine)	30.2 kilograms/hour
	2.1 kilograms/amp-hr

PUMP

Total running hours	4,530 hours
Rated current	2.5 amps
Actual average current	1.05 amps
Total amp-hrs used	4,756 amp-hours
Total energy used	571 kilowatt-hrs
Total water pumped	5,539 cu meters
Water pumping rate	1.18 cu meters/hour
	1.12 cu meters/amp-hr

TOTAL

Total amp-hrs used	32,070 amp-hrs
Total energy used	3,848 kilowatt-hrs

TABLE 1

RECORD JOURNALIER TANGAYE

LeRC 04/30/79

Journee de la semaine		Lundi	Mardi	Mercredi	Jeudi	Vendredi	Samedi	Dimanche
Nom		Fernand	Fernand	Fernand	Fernand	Fernand	Fernand	Fernand
Date		8/6/81	9/6/81	10/6/81	11/6/81	12/6/81	13/6/81	14/6/81
Heure		12h5	12h24	12h38	12h10	12h0	12h39	11h24
(1) Array Ampere-Hours		6574.17	6603.94	6679.35	6766.83	6855.32	6936.72	7007.57
(2) Array Amperes		3.5	3.5	3	12.5	6.5	3.5	3
(3) Mill Ampere-Hours		3527.16	3532.37	3645.09	3725.80	3792.47	3850.32	3901.06
(4) Mill Amperes		0	0	0	0	0	0	0
(5) Mill Hours		1785.6	1790.1	1793.8	1793.4	1803.8	1807.8	1811.3
(6) Pump Ampere-Hours		2174.75	2184.04	2182.12	2193.83	2208.33	2214.97	2222.09
(7) Pump Amperes		0.3.1.9	0	0	0	0	0.3.1.9	0
(8) Pump Hours		0072	0081.2	0088.9	0086.3	0104.3	0110.6	0117.7
Voltage Limit Control	(9) Low Limit	104	104	104	104	104	104	104
	(10) Volts	131	134	134	127	126	131	133
	(11) High Limit	137	137	137	137	137	137	137
System Volts	(12) Low Limit	124	124	124	124	124	124	124
	(13) Volts	130	139	133	126	125	130	132
	(14) High Limit	134	134	134	134	134	134	134
Temperature		103	106	103	103	88	95	97
Compteur d'Eau		06722.9	06732.7	06741.3	06749.1	06752.7	06764.4	06771.6
Reservoir d'Eau		1	1	1	1	1	1	1
Temps		0/10	0/10	6/10	6/10	10/10	0/10	0/10
Heures de fermeture		4h45	4h15	5h50	5h55	6h5	5h30	6h40
Temps restant sur le Moulin		12h35	12h35	12h50	12h45	2h25	1h15	11h25
Module thermistor		5.10	5.10	5.10	5.10	5.09	5.10	5.10
Ambient thermistor		0.14	0.14	0.14	0.14	0.14	0.14	0.14
Bande								
(15) 12 Volt Voltage		14.5	14.5	14.5	14	13.5	14.5	14.5
(16) 12 Volt Current		+2.5	+3	+2.5	+3.5	+2	+3	+3
12 volt amp hour meter		4339.49	4373.55	4408.60	4435.24	4458.97	4494.40	4526.79
Number of DC lights on		4	5	6	3	3	5	5
Total Poids		112.65	133.9	131.95	181.7	154.75	109.25	221.10

FIGURE 6. - TYPICAL TANGAYE DATA SHEET

Mill Performance - The original burr mill and its identical replacement were operated from February, 1979 through August, 1979. During this period, the two mills accumulated 522 hours of operating time and used 440 kilowatt-hours of energy. Data on flour produced by these mills are not available and would be of little value due to the excessive mechanical problems experienced with these mills.

The Bell #10 hammermill, which was installed in September of 1979, has operated for 1,639 hours as of March 29, 1981 and has ground a total of 48,861 kilograms of grain while consuming 2,838 kilowatt hours of energy (17.2 kilograms/kilowatt-hour). The overall grinding rate for this mill has been 30.2 kilograms per hour. Overall, the burr mill/hammermill combination was operational 91% of the time during the first two years of operation.

Variations in use of the mill can be observed in Figure 7. This figure covers only the period of time the hammermill was in operation. The periodic reductions in mill use are attributable to two causes: reduction in electrical power generation due to the module problems mentioned previously, and reduced village demand during the summer months. Insufficient data are available to separate the two causes, although the module problems are believed to predominate. The increase in array size (accomplished in May 1981) will eliminate the problem of shortage of energy and should allow a direct observation of seasonal mill use.

Pump Performance - The pump has operated satisfactorily for the entire period. It has been on-line 97% of the time (the same as the overall system). During this time, it operated for 4,530 hours and pumped 5,539 cubic meters (1,463,237 U.S. gallons) of water while consuming 571 kilowatt-hours of energy. The pumping rate has been 1.18 cubic meters of water pumped per hour of pump operation, or 9.71 cubic meters of water pumped per kilowatt-hour.

A seasonal variation in water use can be seen in Figure 8. This variation is due entirely to changes in village demand during the wet and dry seasons. Although predicted water use was determined at 5,000 liters per day in the dry season (on the basis of a short term measured well recovery rate), actual pumping rates at times approached nearly three times the predicted amount. There is no known time when the pump and well capacity were not sufficient to meet village demand. It should be noted that this curve does not represent variation in total water use by the villagers, but only that taken from this well. During the rainy season (June-October), other water sources closer to many of the village homes appear. These sources are then used instead of this well resulting in reduced demand on the well.

OPERATIONAL EXPERIENCES

The first two years of field operation at Tangaye has yielded valuable experience relative to the design and use of PV systems in a rural Third World environment. These are detailed below according to the different subsystems.

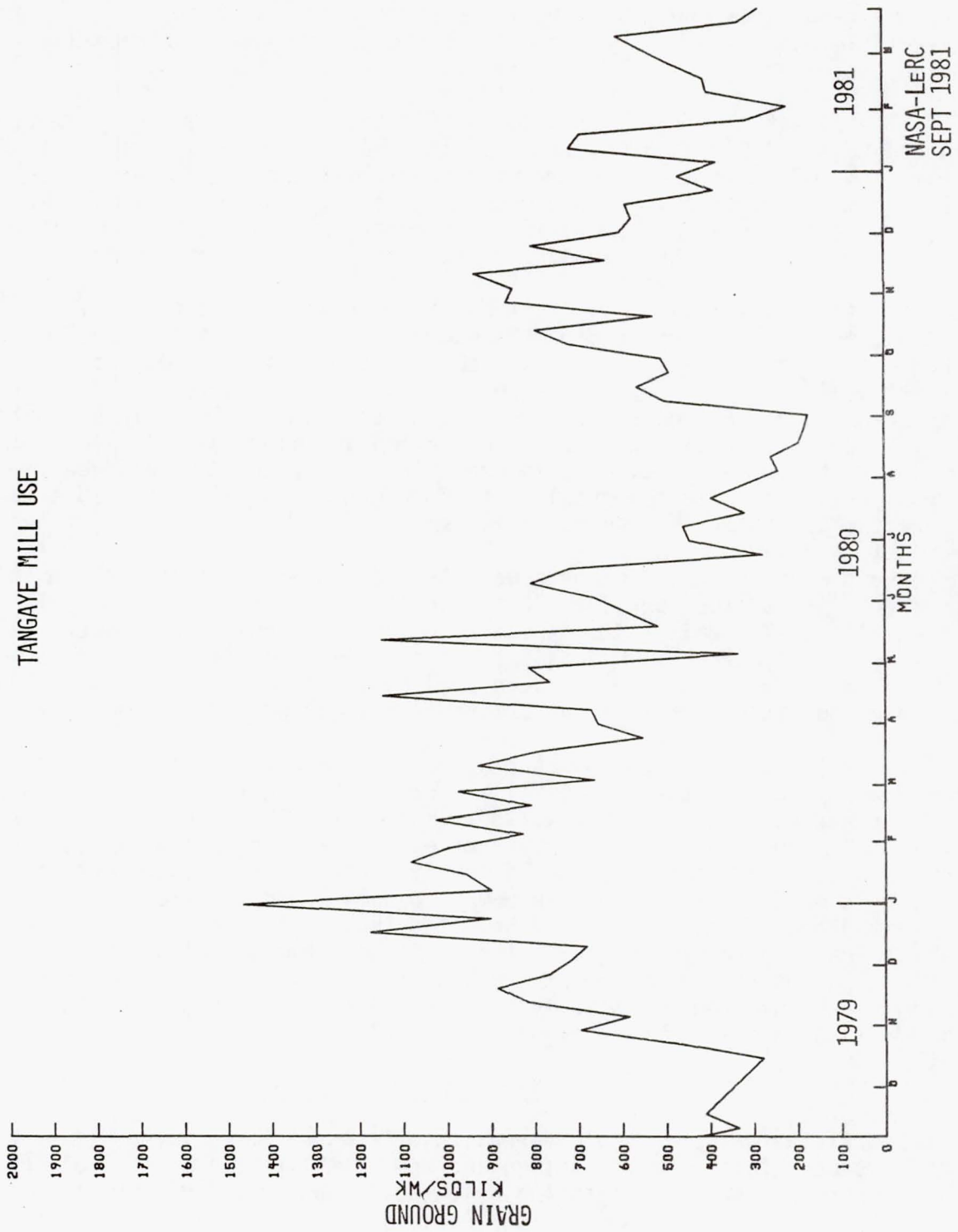


FIGURE 7.

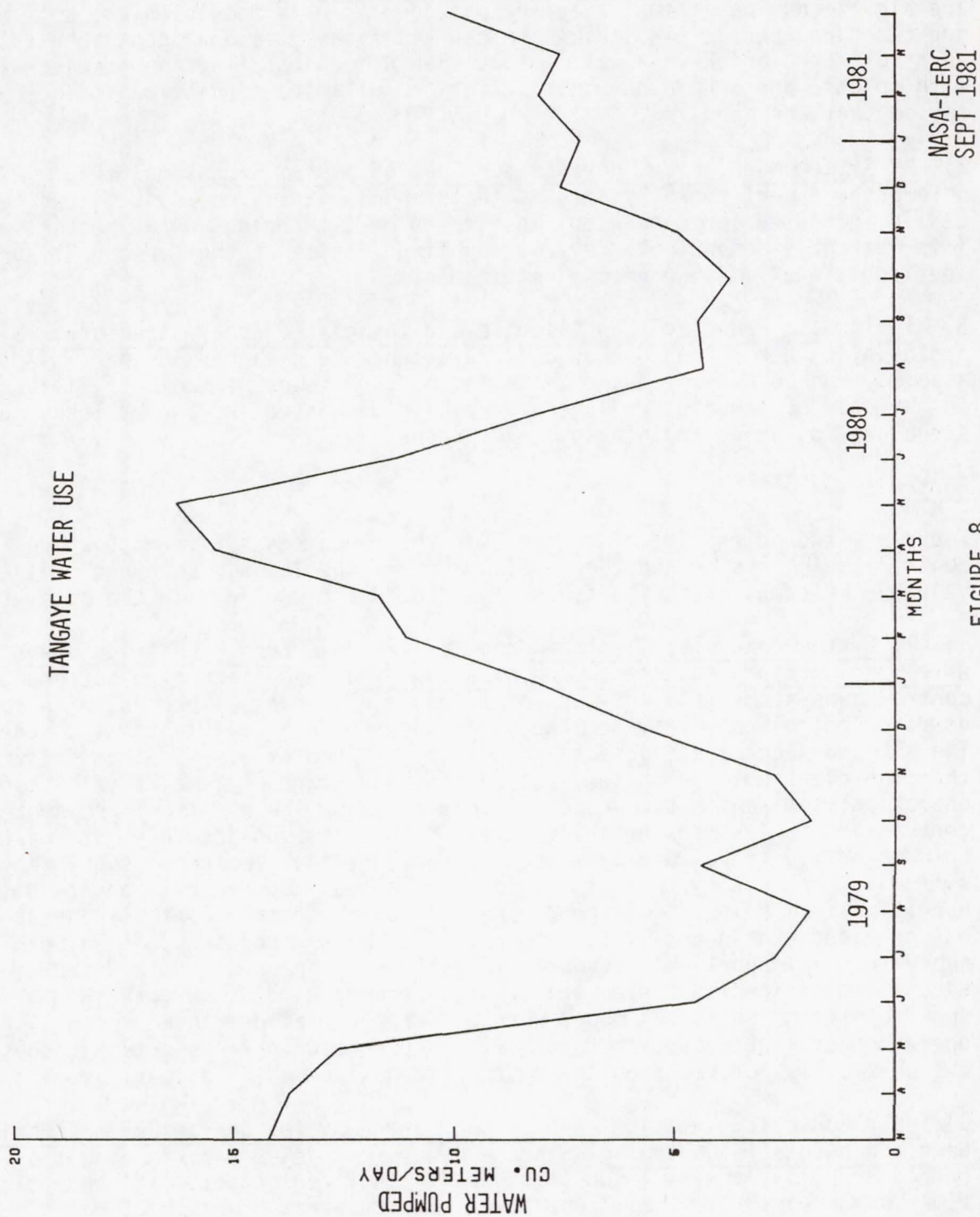


FIGURE 8.

PV Array

- 1) Station Keepers Can Replace Failed PV Modules: Although the solar cells are high technology items, they are packaged in a PV module which, to non-technical people (including African villagers), is analogous to a shingle on a roof or a brick in a wall. Thus when a module fails, they replace it with an ease and confidence that belies the ultimate sophistication of the device they are handling.
- 2) PV System Modularity Provides for Ease of System Expansion: One noteworthy aspect of PV systems is their modularity; i.e., systems can be easily increased (or decreased) in size to meet changing energy requirements. This was aptly demonstrated by the doubling in size of the Tangaye PV array to meet additional milling energy requirements.
- 3) Indigenous Personnel Can Assemble and Install PV Array Structure: System installation demonstrated that an array structure designed for partial on-site assembly can be assembled and installed by indigenous personnel (villagers). In the case of Tangaye, villagers assembled and installed the PV array support structure following training by LeRC personnel

Controls

There are two categories of controls in the Tangaye system; those which control the PV system and those which control the loads. Each has yielded valuable information on the types of and need for controls in the PV systems.

- 1) PV System Controls; Electro-mechanical and Electronic Control Subsystems Have Complementary Advantages and Disadvantages: There are two alternate control subsystems (electro-mechanical and electronic) either of which can be used to control the PV system and which operate in a fully automatic mode. The electro-mechanical subsystem has a higher probability of parts failure than the electronic subsystem, but has the advantage of 2 modes of backup operation; semi-automatic and completely manual. The electronic subsystem, conversely, is less susceptible to failure, but is considerably more difficult to work around if failure does occur. However, the electronic subsystem has sufficient redundancy so that a failure of one of the control modules disrupts operation from only 17% of the PV array. Having the two control subsystems has provided continuous PV system control despite minor problems in both subsystems. In particular though, the station keepers understand the electro-mechanical subsystem well enough to have used it in both the semi-automatic and manual modes when a component failure interrupted automatic operation of that subsystem (and during a period when the electronic subsystem was physically removed from the system for design modifications).
- 2) Load Controls: Station Keepers Can Manage System Energy Balance Obviating Need for Automatic Controls: Since a PV system yields a fixed amount of energy annually, the mill subsystem design included an automatic resetting timer which would limit mill operating time to a fixed number of hours per day. In sizing the PV system and loads, it was determined that the PV system could support 8 hours of burr mill operation every day. The timer that was included in the system design and original installation would allow up to 8 hours/day of actual motor operation and then inhibit further motor operation

for that 24 hour period. It automatically re-set itself at midnight and always displayed the number of hours, minutes, and seconds of milling time remaining that day. Although the timer functioned properly during all tests at the LeRC, soon after installation in Tangaye it began to function erratically and eventually had to be disconnected. In place of the automatic controls, LeRC personnel instructed the station keepers how to calculate the daily PV array/combined loads energy balance and then determine the number of hours of milling time available the next day. This manual method of mill time determination is actually superior to the "fixed-time" timer in that it allows increased mill time during periods of high insolation and, conversely, reduced mill time during the cloudy season, thus lessening the risk of excessive battery discharge. The station keepers quickly learned how to manage the system energy and have been managing it since March of 1979. This manual energy management proved especially useful when the photovoltaic modules began failing and PV array output began decreasing. The result of this experience with manual energy management is that automatic load limiting controls such as the timer are no longer considered necessary.

Instrumentation and Data

The Station Keepers Maintain Excellent Records: The Tangaye system has both panel meter instruments and an automatic data logger. The station keepers were provided with a standard data sheet and instruction in how to take daily data from the panel meters and to keep records of the milling operation. Their performance, in terms of recording and forwarding these data, has been superb and emphasizes the competence and reliability of interested local people in providing information from such an experimental project.

Batteries

Battery Rooms Need Concrete Floors: Although LeRC designs anticipated a concrete floor in the battery room of the mill/battery building, a shortage of cement and assurances that a native tamped earth floor would support the main battery resulted in the battery racks being placed on the prepared earth floor. During the 1980 rainy season, the local water table rose to within 18" of the ground level and the battery racks started to lean over with attendant risk of damage to the battery cells and injury to maintenance personnel. Local AID personnel with help from the station keepers had to provide emergency shoring. As a result of this experience the battery room floor was concreted in May 1981.

Mill Subsystem

1) Burr Mills Are Unacceptable in Commercial Flour Production Applications: As was described earlier the burr mill originally selected for this system, although capable of grinding flour of satisfactory fineness, is not suitable for such a production operation due to the high component wear rates imposed on the mill when fine flour is being produced and to the high noise levels associated with such production. The hammermill was determined to be superior in all respects. As an aside, since the introduction of the hammermill at Tangaye in 1979, hammermills are now being sold commercially in Ouagadougou.

2) Women Do Not Wish to Sacrifice Fineness of the Ground Product for Mechanical Milling: From the outset, women expressed a strong desire for the mechanically ground product to be as fine as that from their grinding stones. That, in fact, was the principal cause for the demise of the burr mills.

3) Feed Rate Controls: The Millers Use Mill Motor Current to Regulate Feed Rate: Several different grains are brought to the mill and the moisture content of lots of each grain vary. It is difficult, therefore, to establish fixed adjustments for the feed gate in the mill feed hopper. Too high a feed rate overloads the motor and results in diminished throughput. Too low a rate underutilizes the mill. After observing initial milling operations, LeRC personnel installed, next to the mill, an ammeter that measures mill motor current and instructed the millers in how to adjust the feed rate to optimize mill and mill motor operation. The millers quickly became proficient in regulating feed rates and optimizing mill throughput.

Pump Subsystem

1) Well Yield Data Can Be Unreliable: Data from the GOUV indicated that a typical yield for shallow (10-15 meter) wells in the Tangaye area was $5\text{m}^3/\text{day}$. During the 1978 site visit, LeRC engineers performed a short term (1 hour) yield test on a half-full well that exactly corroborated GOUV data. Since installation of the system, pumping rates have been as high as $16\text{m}^3/\text{day}$ and observations indicate that a higher rate could be achieved if the well were pumped all night. The difference between test and actual pumping rates apparently develops when the well is pumped at mid-level rather than at its lowest level, i.e., when it is "empty" and being replenished from a lower level of the aquifer.

2) Pumped Vs. Drawn Water Does Not Encourage Waste: A concern during system design was that people would tend to "let the water run" from the tank, whereas lifting the water encourages conservation to minimize labor input. Spring-loaded faucets were thus specified for the water tank. Observation has shown that the people do not waste any more water from the tank than when drawing by hand.

General

1) System Repairs: The station keepers have been able to effect mechanical repairs to the mill and have proven to be rather adept at improvising fixes when, for instance, spare parts for the burr mill were expended. Repairing (not replacing) electrical devices is still beyond their sphere of understanding and experience.

2) Upkeep: The station keepers have done an excellent job of maintaining the overall facility and there have been no instances of vandalism to any part of the system.

3) Training: Without the volunteered help of a Peace Corps worker who is fluent in both French and the local African dialect, training would have been considerably more difficult, but not impossible. All of the training objectives were met and subsequent experience has shown that with such training, the local people are capable of operating and managing such a system.

4) Pride and Enthusiasm: A great deal of credit for the successful and prosperous operation of the system has to be attributed to the pride the villagers have in the system. The uniqueness of the PV aspects of the system has certainly contributed to their attitudes. The planning, preparation, training and follow-up monitoring must also have engendered a feeling of involvement which, since planning began, gave the villagers the time to become mentally and socially prepared to accept and benefit from the system.

CONCLUDING REMARKS

The Tangaye PV system provided sufficient electricity during the first two years of operation to enable the grinding of about 55 metric tons of finely ground flour and the pumping of over 5500 cubic meters of water from the 10 meter deep well.

Upon completion of the initial two-year project period, AID and the Government of Upper Volta entered into an agreement calling for a continuation of the project until March of 1983. Under the terms of the agreement, NASA LeRC was given the responsibility for refurbishing and expanding the PV system. Using PV modules of a different design provided as surplus by the Department of Energy, the renovation was implemented by LeRC during April - June of 1981, increasing the system peak power from 1.8 to 3.6 kW peak. In addition, an improved hammermill having over twice the grinding efficiency of the existing hammermill was installed and training of the local millers, a new station keeper and GOUV personnel was completed. The GOUV personnel have now assumed full responsibility for monitoring and maintaining the Tangaye system.

The expansion of the Tangaye system is significant in that it represents the first time (to our knowledge) that a PV system has been scaled-up by a factor of two in a field operational setting. This demonstration of the modular characteristics of PV systems required only increasing the number of PV panels, replacing a few circuit breakers and a current shunt and adjusting some voltage settings.

In summary, the Tangaye project has provided a benchmark for the utilization of photovoltaics in a rural setting and is now being viewed by many as a significant demonstration of renewable energy technology for the developing world.

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APPENDIX A - RESULTS OF GRINDING TESTS USING
A C.S. BELL COMPANY #60 BURR MILL

by J. E. Martz

Introduction

The United States Government, acting through the Agency for International Development (USAID), has entered into an agreement with the Government of the Republic of Upper Volta, West Africa, to provide a Solar Energy Demonstration Project (Project No. 698-0410-13).

This project consists of a photovoltaic (PV) system which provides electrical power for grinding grain and pumping water in the village of Tangaye. The project will complement an existing project, Studies of Energy Needs in Food Systems (No. 931-0234) which will study the effects of such an installation on food production and food processing habits in a rural African village.

The NASA-Lewis Research Center (LeRC) has an agreement with USAID (PASA NASA DSB-0234-2-78) to provide and install the PV system, mill and pump for the project. A C.S. Bell Company (Tiffin, Ohio) model No. 60 burr mill was selected for use in the project. Tests were run at LeRC in April and May 1978, to evaluate suitability of this mill to grind flour of acceptable quality and throughput for the villagers. This report documents results of the LeRC tests.

Purpose

The purpose of these tests was to evaluate the fineness of the ground product and throughput of a C.S. Bell Co. #60 burr mill. The LeRC had contacted various users of the #60 mill, but none had used the mill to grind flour. It was, therefore, deemed necessary to grind samples of Upper Volta grain to determine the performance characteristics of the #60 burr mill.

Mill Description

The C.S. Bell #60 burr mill selected for this project is shown in Figures 1 and 2. The mill shaft rotates a 5½" diameter cast iron burr plate against an identical stationary plate mounted in the mill housing. Grain from a hopper located on top of the mill is fed by an auger through a hole in the center of the stationary plate and is ground as it passes between the plates. An adjustable thumbscrew, disc, and ball pressing against the end of the shaft force the plates together and regulate the fineness of grind. An adjustable shutter in the feed hopper regulates the feed rate. The mill is driven by a 1 hp 120 VDC electric motor through a belt drive.

Procedure

Preliminary tests used locally obtained (U.S.) red millet, milo, and wheat. Later tests used millet, sorgho (sorghum) and maize obtained from Upper Volta. The mill was installed and set up according to the manufacturer's instructions and several initial runs using U.S. red millet were made to set the machine adjustments. To get the finest output from the mill, the "very fine" burr plates were installed in the mill and tightened until a moderate, but not excessive, amount of heating of the output flour was noted. The feed shutter was then adjusted for a rate which did not overload the machine. Both adjustments were then locked in place for the remainder of the runs. This might have resulted in less than optimum adjustment for a particular grain, but it allowed comparison between grains for the purposes of testing.

It should be noted that the exact adjustment of the tightness of the burr plates is neither easily measured nor accurately reproducible. Also, the feed shutter has no markings to enable reproducible feed rate settings. The shutter could be scribed with lines to correct this situation if it were deemed desirable after some operating experience has been obtained.

Two 0.5 Kg samples of each grain were prepared. One sample of each grain was passed through the mill one time, and one sample two times. A 0.1 Kg sample of each resultant ground product was then sieved through a series of 8 inch U.S. Standard sieve screens using Tyler equivalent screen meshes of 20, 40, 60, 70 and 100. The sieve stack containing the sample was placed on a vibrating table for 15 to 30 minutes until the flour was separated according to particle size. The percentage of flour passing through each screen was determined by weighing. This gave a means of comparing the fineness of the resulting flours. For baseline comparison, a sample of "mixed sorgho blanc/petit mil" flour from the Tangaye village Chief's grinding stone, referred to as "UV ground sorgho", and samples of U.S. commercially ground white flour and whole wheat flour were also sieved.

Grinding Observations

The time required for each sample to pass through the mill was recorded and the grinding rate noted in Table 1. In all cases, the motor was started, then the grain was poured into the hopper. On the first pass, both the U.S. and Upper Volta millet samples could be quickly poured into the hopper with the hopper slide controlling the

throughput. Doing the same for the milo, wheat, sorgho, or maize samples overloaded the machine and stalled the motor. Therefore, these latter samples had to be poured in slowly while the machine was running. In all cases, on the second pass, the input sample tended to build up on the hopper slide and needed to be manually scraped off the slide to maintain a reasonable throughput. This indicates the need for slide adjustment for different grains, and for different passes of the same grain. The type of grain had a considerable effect on grinding rate, but most results fell generally within the manufacturer's advertised range of grinding rates (see Table 1).

Screening Observations

For the finer flours, a tendency was noted for flour to adhere to the screens, thereby complicating the measurement process. The adhering flour was of a very fine, dustlike, consistency. For the purpose of this test, the flour adhering to the screens, was included with that passing through the 100 mesh screen.

Figure 3 shows a comparison of the UV ground sorgho flour, the U.S. commercially ground whole wheat flour, and the U.S. commercially ground white flour used for baseline comparisons. Both commercial flours are considerably finer than the UV ground sorgho flour. Nearly 100% of the U.S. commercial white flour passed through all the screens.

Figure 4 shows the comparison of the UV ground sorgho flour with U.S. red millet. Once-ground U.S. red millet is more coarse than the UV ground sorgho flour, while the twice-ground U.S. red millet has a very similar consistency to the UV ground sorgho flour. Visually, however,

the U.S. red millet flour appears more coarse than the UV ground sorgho flour due to the red bran (hulls) in the millet flour. The UV ground sorgho flour appears to have little bran in it and may have been made from dehulled grain. This would tend to bias a fineness comparison in favor of the UV ground sorgho flour.

Figure 5 shows the comparison of UV ground sorgho and U.S. milo flours. Milo is about the same size and shape as UV sorgho, but has a red hull. In the test, the U.S. milo flour left more residue on the finer screens than the UV ground sorgho resulting in a less favorable fineness comparison. If the U.S. milo had been previously dehulled, it might have compared more favorably with the UV ground sorgho. The sorgho residue on the coarser screens appeared to be mostly broken grain, whereas the milo residue was mostly hulls.

Figure 6 shows the comparison of UV ground sorgho and U.S. wheat flours. The wheat left more bran on the coarse screens than the sorgho, but at the same time, passed more flour through the fine screens.

Figure 7 shows the comparison of UV ground sorgho flour and flour ground in the Bell #60 mill from Upper Volta millet. The Bell mill ground UV millet flour was somewhat more coarse than the UV ground sorgho flour and also more coarse than the flour ground from U.S. millet.

Figure 8 shows the comparison of UV ground sorgho and UV sorgho ground in the Bell #60 mill. The flour from the Bell mill was considerably more coarse than the UV ground sorgho flour in this instance.

Figure 9 shows the comparison of the UV ground sorgho and UV maize flour ground in the Bell #60 mill. Again the flour from the mill was more coarse than the UV ground sorgho flour.

The relative coarseness of the later ground flours, led to speculation that the coarseness might be due to loosening of the mill burr plates due to wear-in of the mill parts. By the time this difference was noted, the mill was being crated for shipment, and further testing was not possible. To check this theory, samples of sorgho flours were sieved which had been ground in preparation for a planning visit to Upper Volta in February of 1978. These samples had been ground from small quantities of Upper Volta grain obtained previously. They had been ground using the same mill, but not using the same slide and burr plate settings used for the tests described herein. Figure 10 shows the comparison of these flours ground once, twice, and three times with the UV ground sorgho as reference. This shows that a finer flour was obtained during early 1978, and tends to confirm the theory that the mill plates were worn slightly by the time tests in this report were completed.

It is interesting to note that during the February 1978, site visit, the women of the Tangaye village were asked to compare these three flour samples from the Bell #60 mill with their own flour. In their judgment, the once ground sample was coarser than their own flour, the twice ground was about the same, and the thrice ground sample was finer.

Summary

These tests indicate that for this demonstration project, the C.S. Bell Model #60 burr mill should be able to provide a satisfactory product at an acceptable throughput rate. The tests also show that the mill is capable of grinding grain at least as fine as the native ground product by using a 2-pass grinding procedure while providing an acceptable throughput.

In general, the residues on the coarse screens (#20 and #40) consisted mostly of bran (hulls). The U.S. red millet residue on the #60 screen appears to be approximately $\frac{1}{2}$ bran (visual estimate), while the U.S. milo residue on the #60 screen appeared to be less than $\frac{1}{3}$ bran. The hulls of the three African grains were lighter in color, thus making it more difficult to judge the relative amounts of hulls on the various screens, but, in general it appeared that most of the hulls were on the coarser screens. It may, therefore, be possible to accomplish some dehulling of the grain by grinding it fairly coarsely and screening it through a coarse screen or winnowing it before further grinding. If this is practical, and the resulting product is acceptable to the villagers, the mill could provide an added benefit by relieving the women of the dehulling task.

TABLE I
GRINDING RATES
USING C.S. BELL COMPANY #60 BURR MILL

Grain	Grinding Rate Kilograms/hr.	
	Single Pass*	Double Pass
U.S. Red Millet	114.6	46.7
U.S. Milo	55.7	32.7
U.S. Wheat	40.3	18.5
African White Millet	83.72	48.65
African Sorgho	92.31	52.94
African Maize	59.02	48.65

*Manufacturer's advertised grinding rate is 45.4 to 136.1 Kgm/hr for single grinding depending on type of grain and fineness of grind.

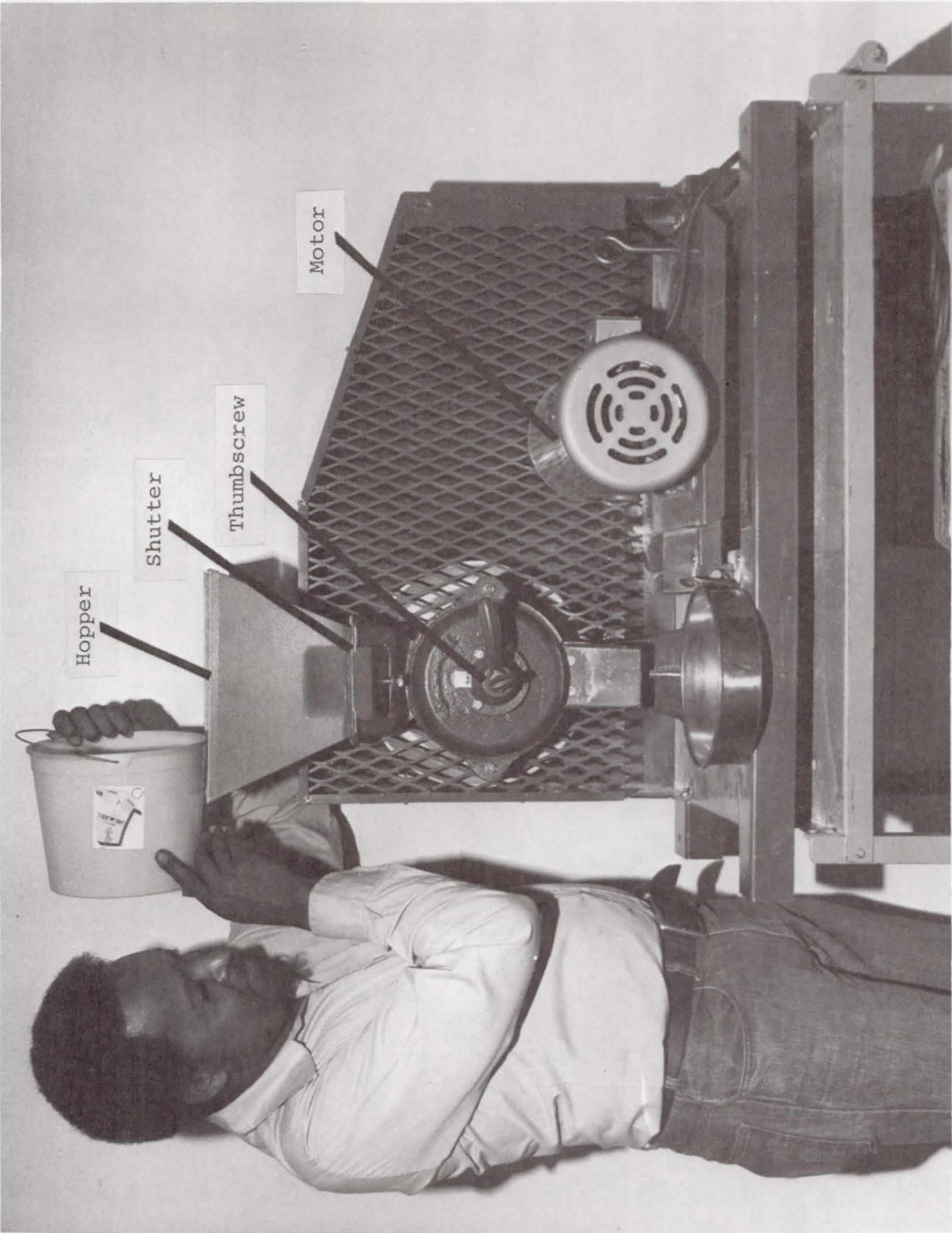


Figure 1

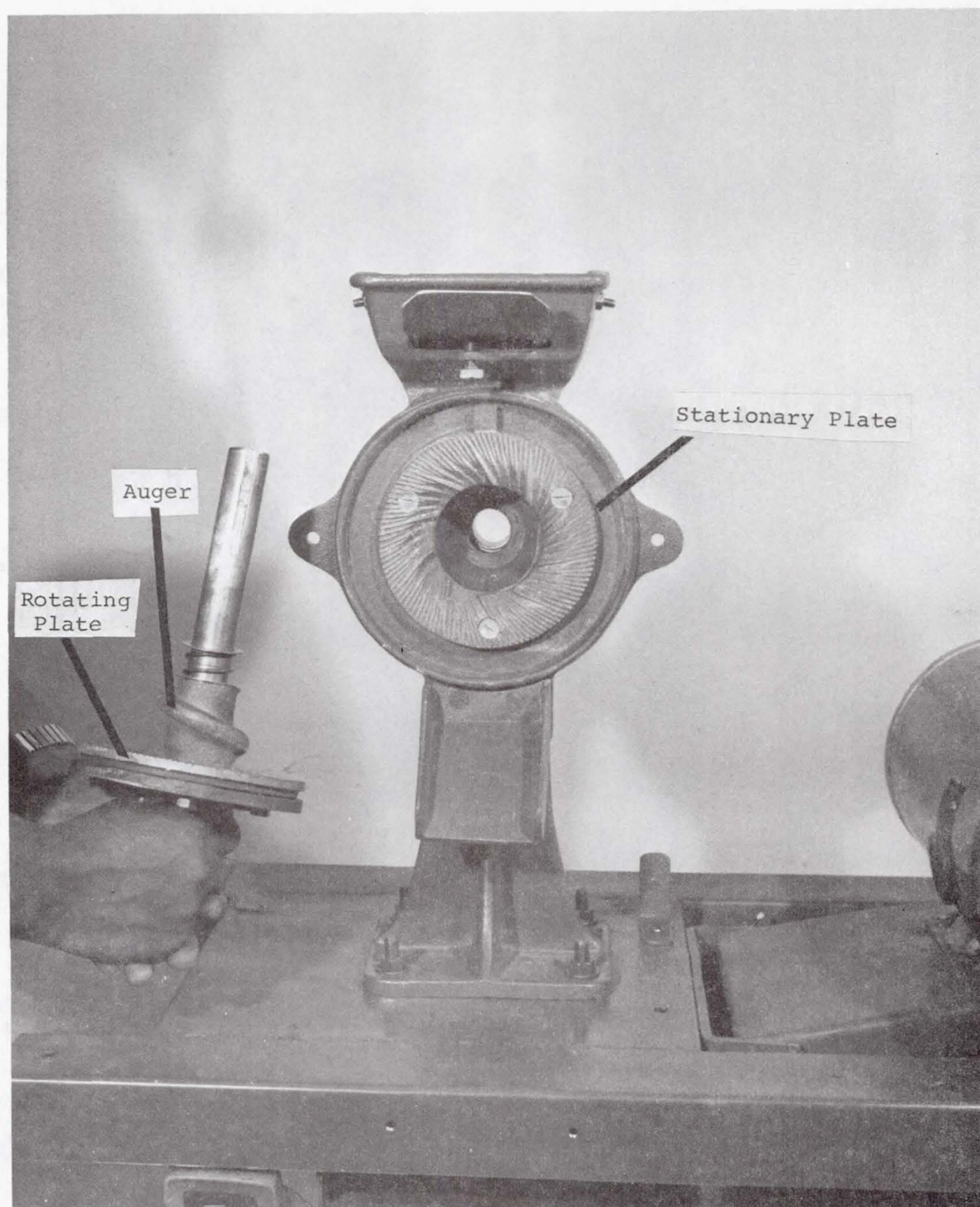


Figure 2

FLOUR COMPARISONS

UV GROUND SORGHO FLOUR

U.S. Commercially ground Whole Wheat Flour

U.S. Commercially ground White Flour

U.S. Commercial White Flour

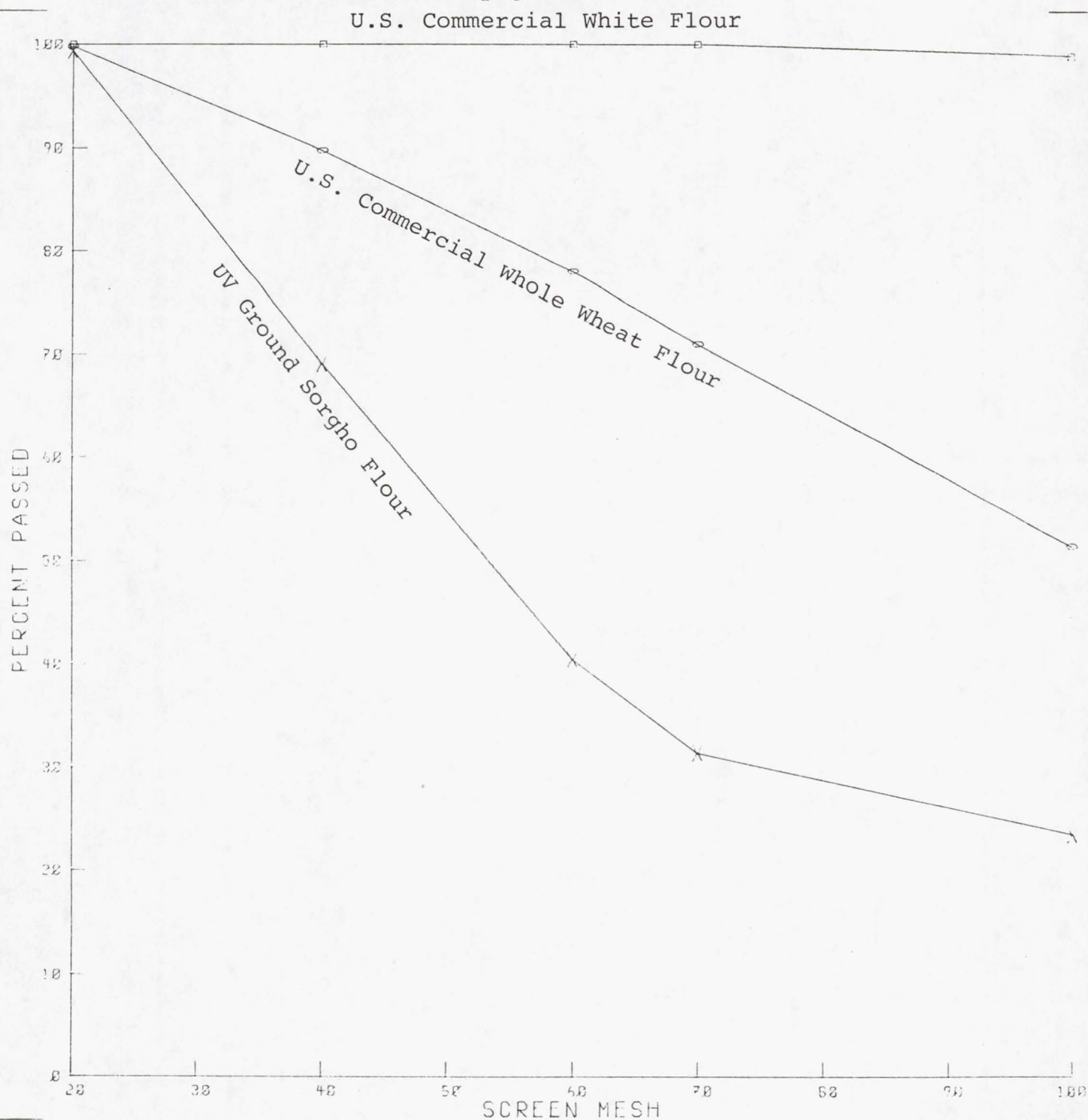


Figure 3

FLOUR COMPARISONS

UV Ground Sorgho Flour
U.S. Red Millet

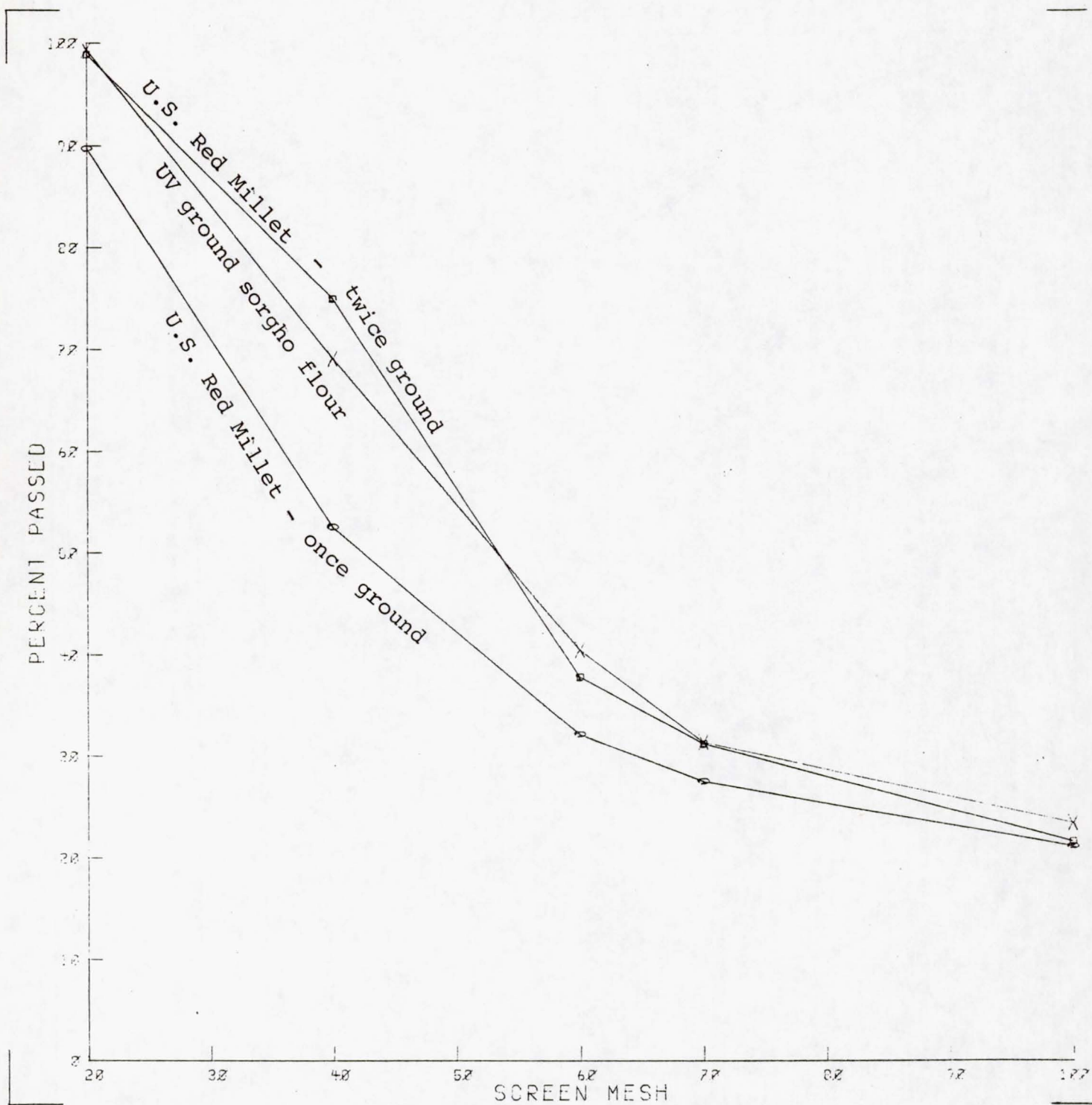


Figure 4

FLOUR COMPARISONS

UV Ground Sorgho Flour
U.S. Milo Flour

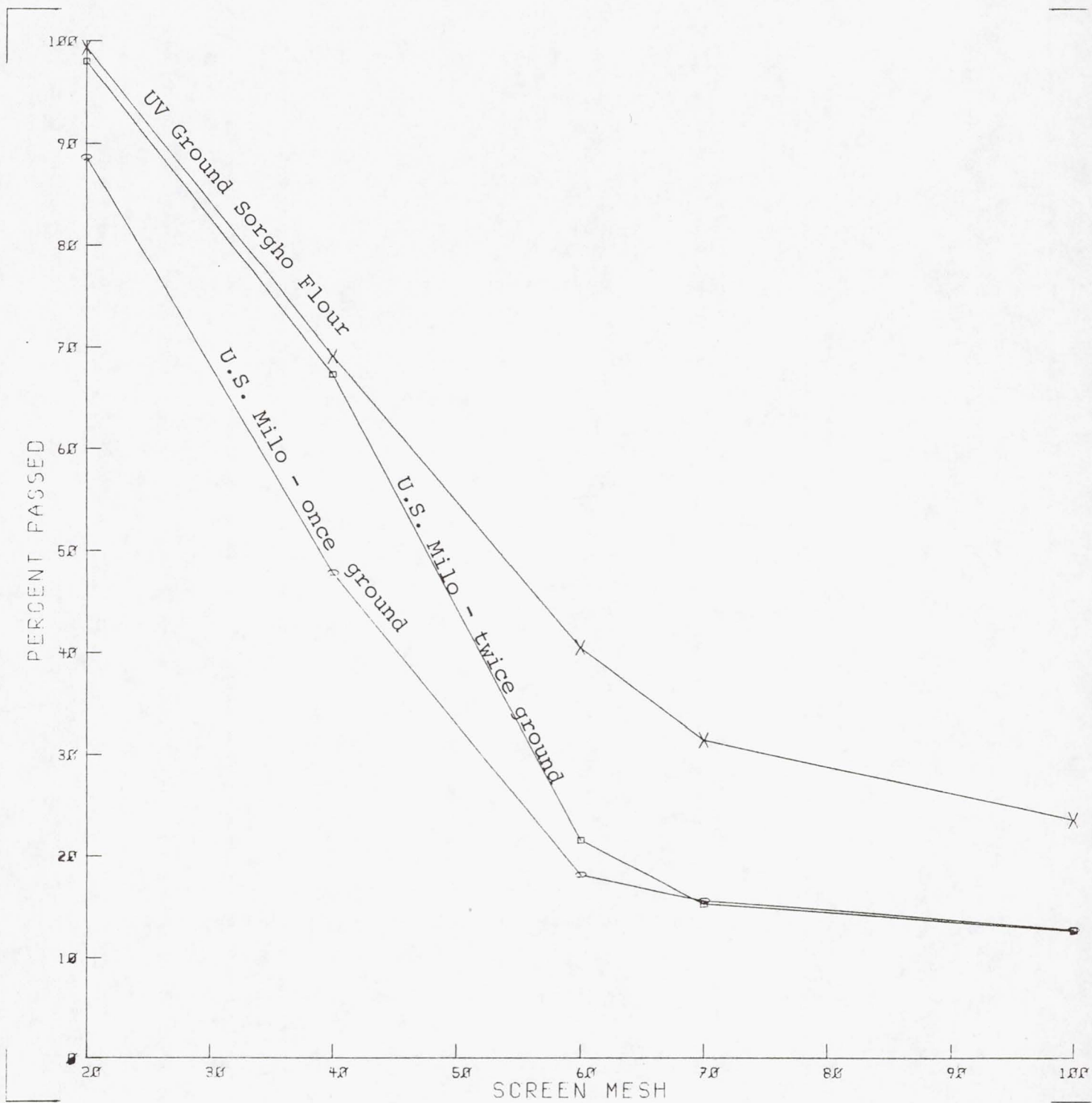


Figure 5

FLOUR COMPARISONS

UV Ground Sorgho Flour
U.S. Wheat Flour

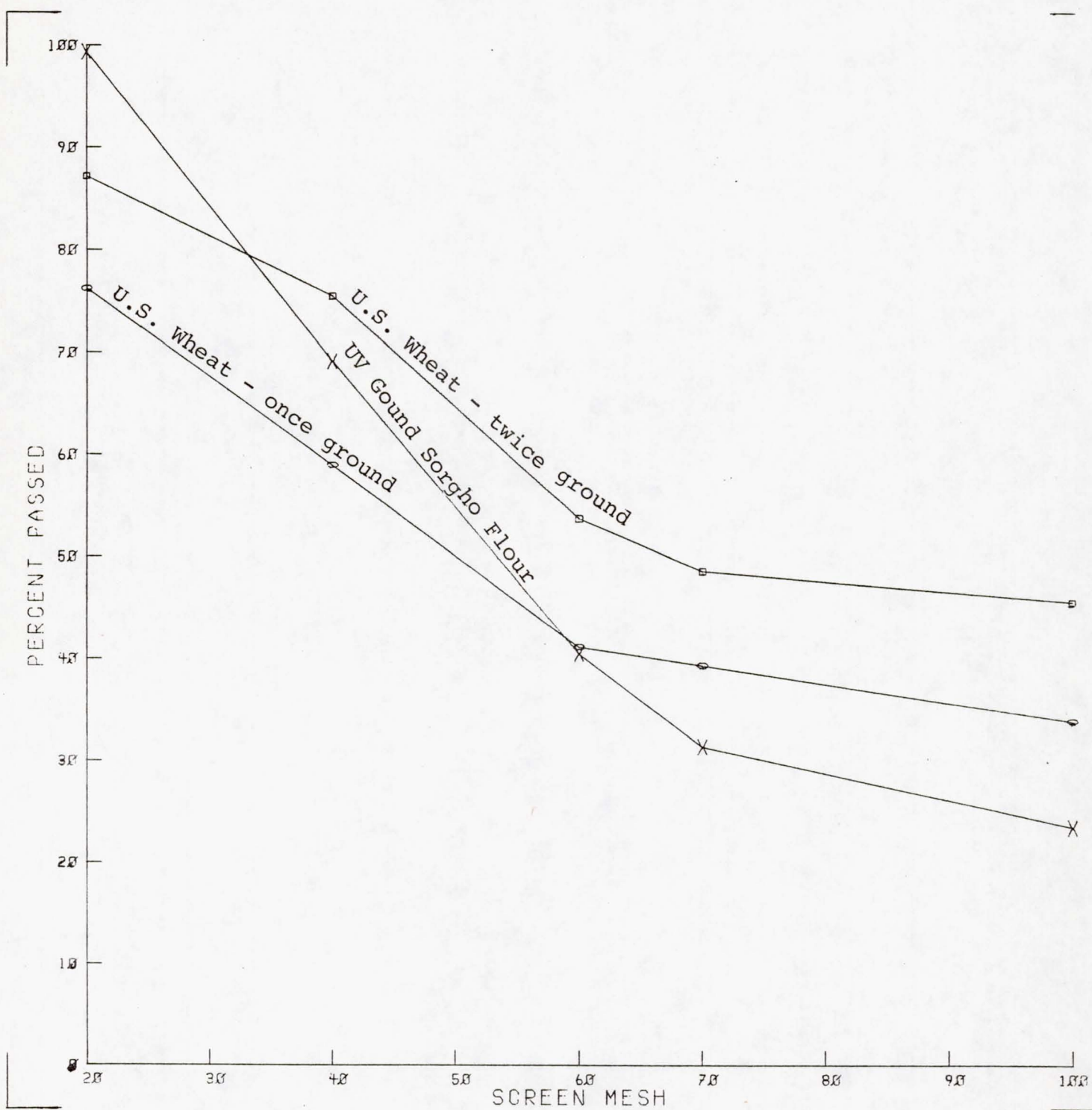


Figure 6

FLOUR COMPARISONS

UV Ground Sorgho Flour
UV Millet Flour

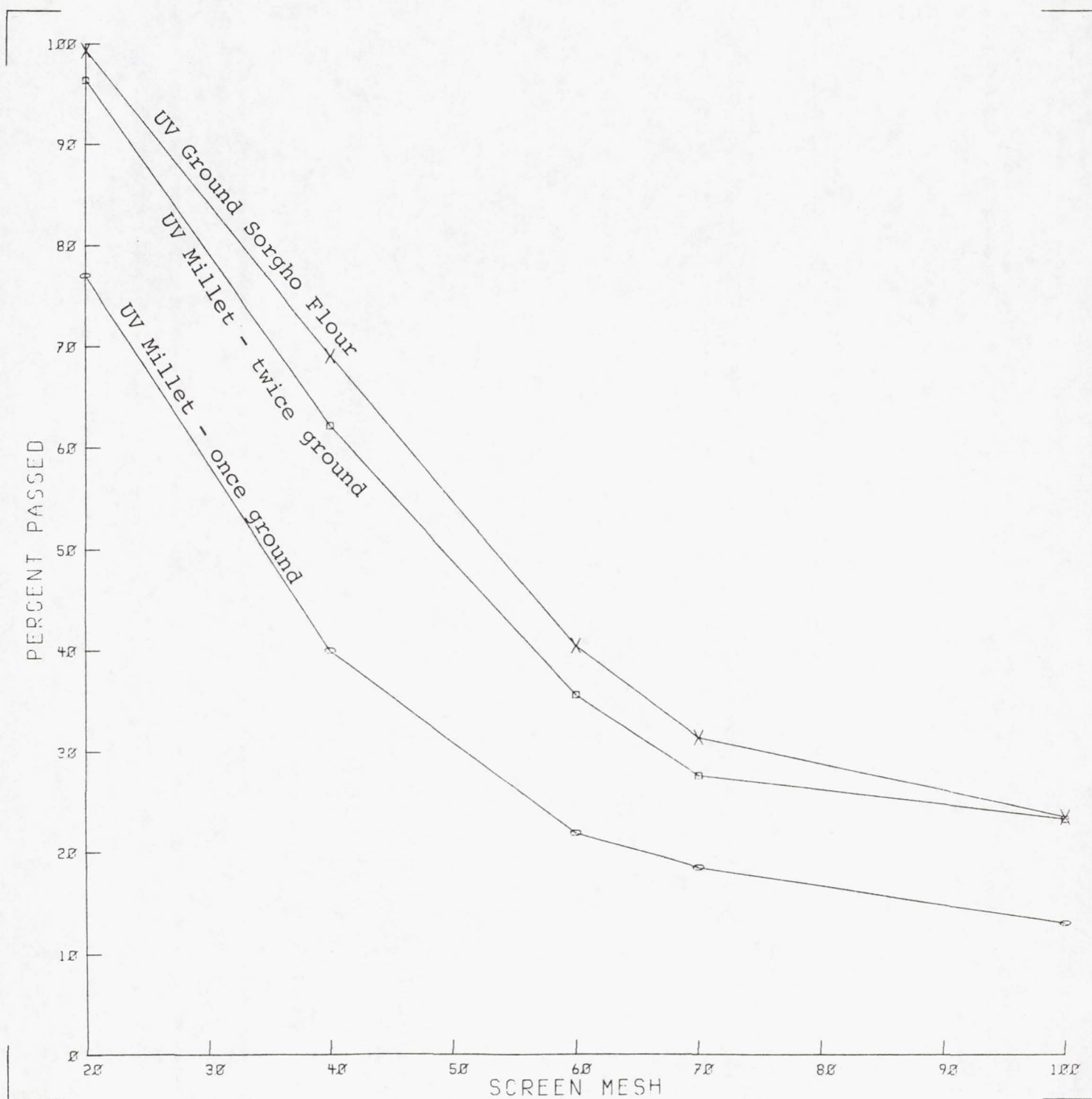


Figure 7

FLOUR COMPARISONS

UV Ground Sorgho Flour
UV Sorgho Flour

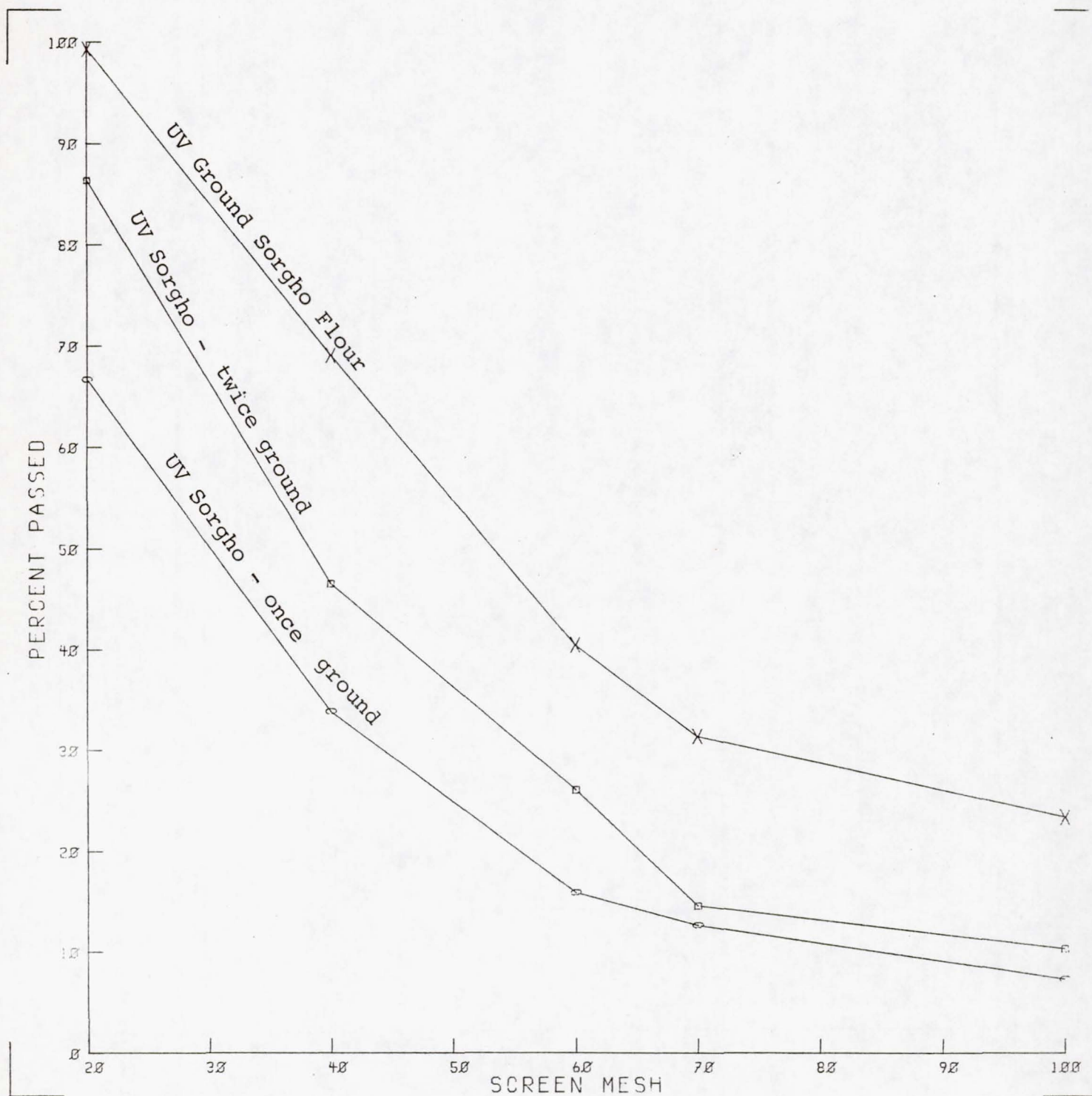


Figure 8

FLOUR COMPARISONS

UV Ground Sorgho Flour
UV Maize Flour

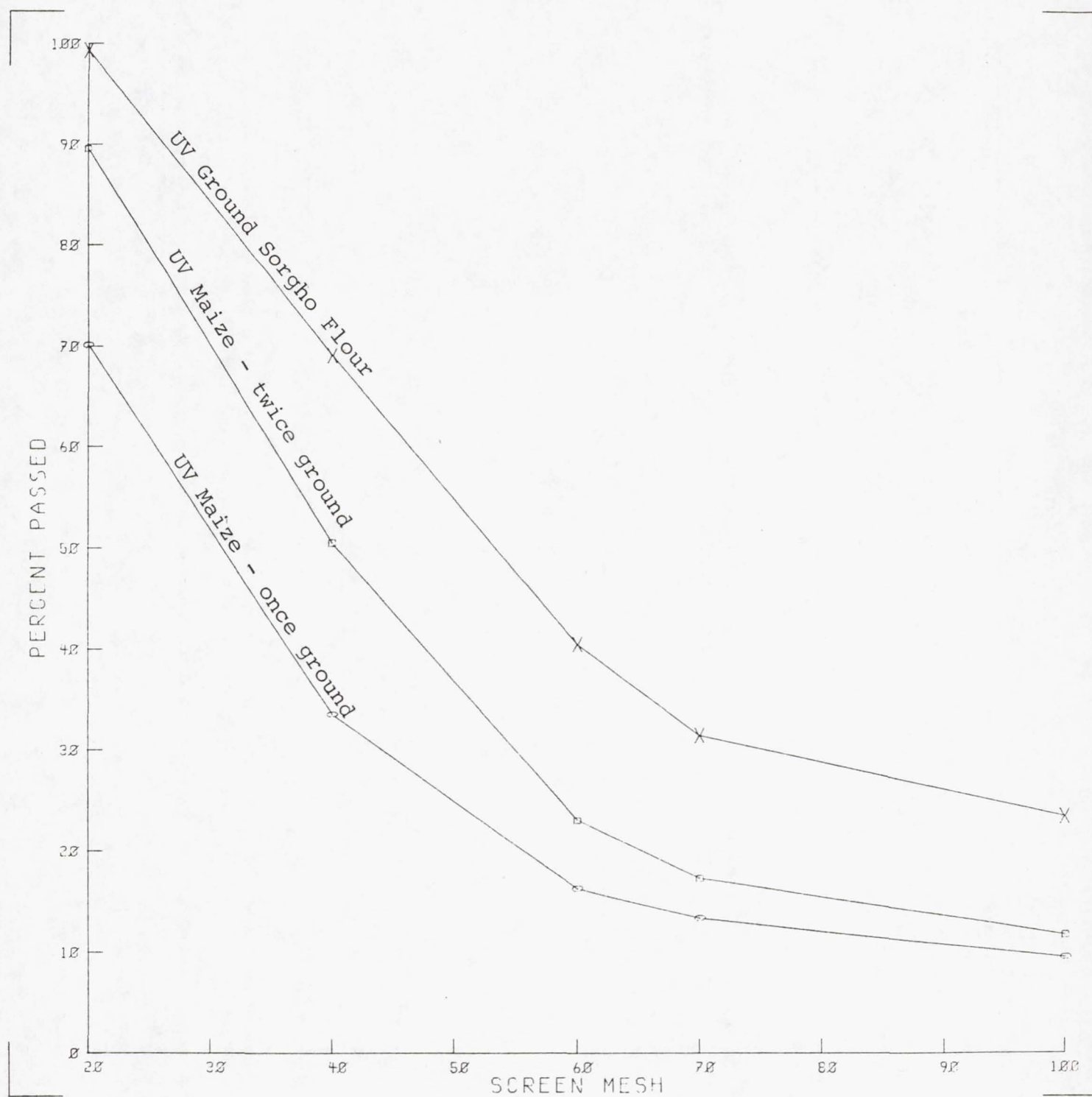


Figure 9

FLOUR COMPARISONS

UV Ground Sorgho Flours
UV Sorgho Ground in Preparation for Planning Visit

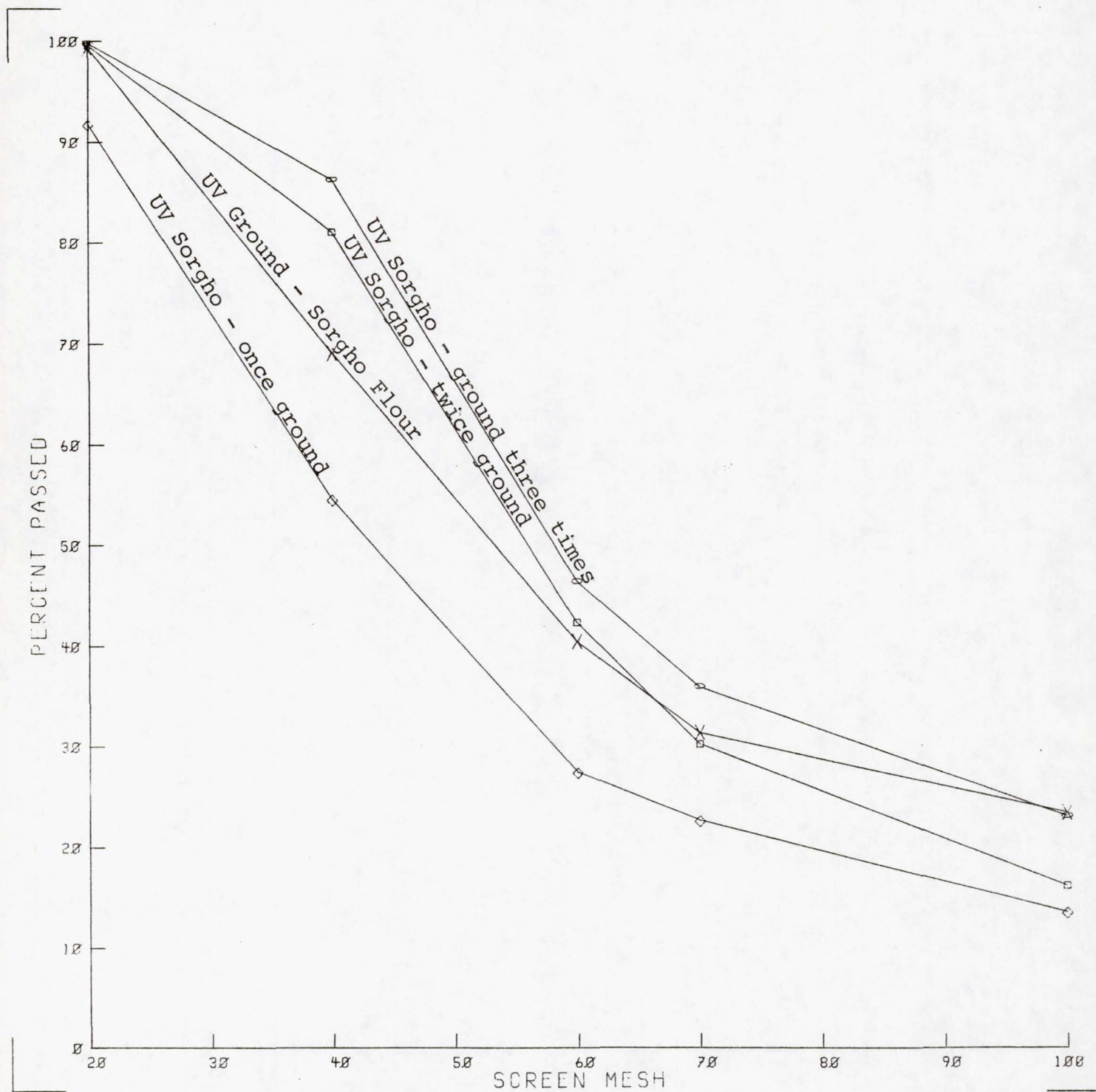


Figure 10

APPENDIX B - RESULTS OF GRINDING TESTS USING A C.S. BELL COMPANY #10 HAMMERMILL

by J. E. Martz

INTRODUCTION

The NASA-Lewis Research Center (LeRC) is currently managing a number of Photovoltaic (PV) application demonstration projects for the U.S. Department of Energy (DOE) and Agency for International Development (AID). Although both programs include design, fabrication and installation of stand-alone PV systems, the DOE program also addresses technology development related to stand-alone PV systems.

Part of the technology development effort is to identify and, where necessary, test energy efficient loads which could be used with PV systems. One type of load appropriate to the needs of villagers in developing countries (particularly West Africa) is a flour mill.

In support of a LeRC/AID PV system project in Upper Volta, West Africa (Ref. 1), the LeRC procured three flour mills to evaluate their throughputs, energy consumption, and the fineness of the ground product.

This report documents the results of the tests on the C. S. Bell Co. #10 Hammermill. References 2 and 3 document the test results of a C.S. Bell Co. #60 burr mill and a Jacobson 120-B Hammermill.

PURPOSE

The purpose of these tests was to evaluate the throughput, specific energy consumption, and fineness of the ground product of a C.S. Bell Co. #10 bottom discharge hammermill. Samples of locally obtained U.S. grains were ground to determine the performance characteristics of the mill.

MILL DESCRIPTION

The C.S. Bell #10 hammermill is shown in Figures 1 and 2. The mill shaft rotates a set of hardened steel hammers within the mill housing. The grain is ground as it is impacted by the hammers against a cast iron breaker plate located in the upper part of the mill and a semi-circular screen comprising the bottom half of the mill. As the grain is ground into flour, it passes through the screen into a discharge chute and out of the mill. The fineness of the grind is determined by the size of the holes of the mill screen. An adjustable shutter in the feed hopper regulates the feed rate. The mill is driven by a 3hp electric motor through a belt drive.

(1) Solar Energy Demonstration Project (Project No. 698-0410-13)
complementing project Studies of Energy Needs in Food Systems (No. 931-0234)
and implemented under PASA NASA DSB-0234-2-78.

(2) Results of Grinding Tests using a C. S. Bell Company #60 Burr Mill: James E. Martz Project Report 4210-046 August 1979.

(3) Results of grinding tests using a Jacobson Machine Works Model 120-B hammermill: James E. Martz. Project Report 4210- To be published.

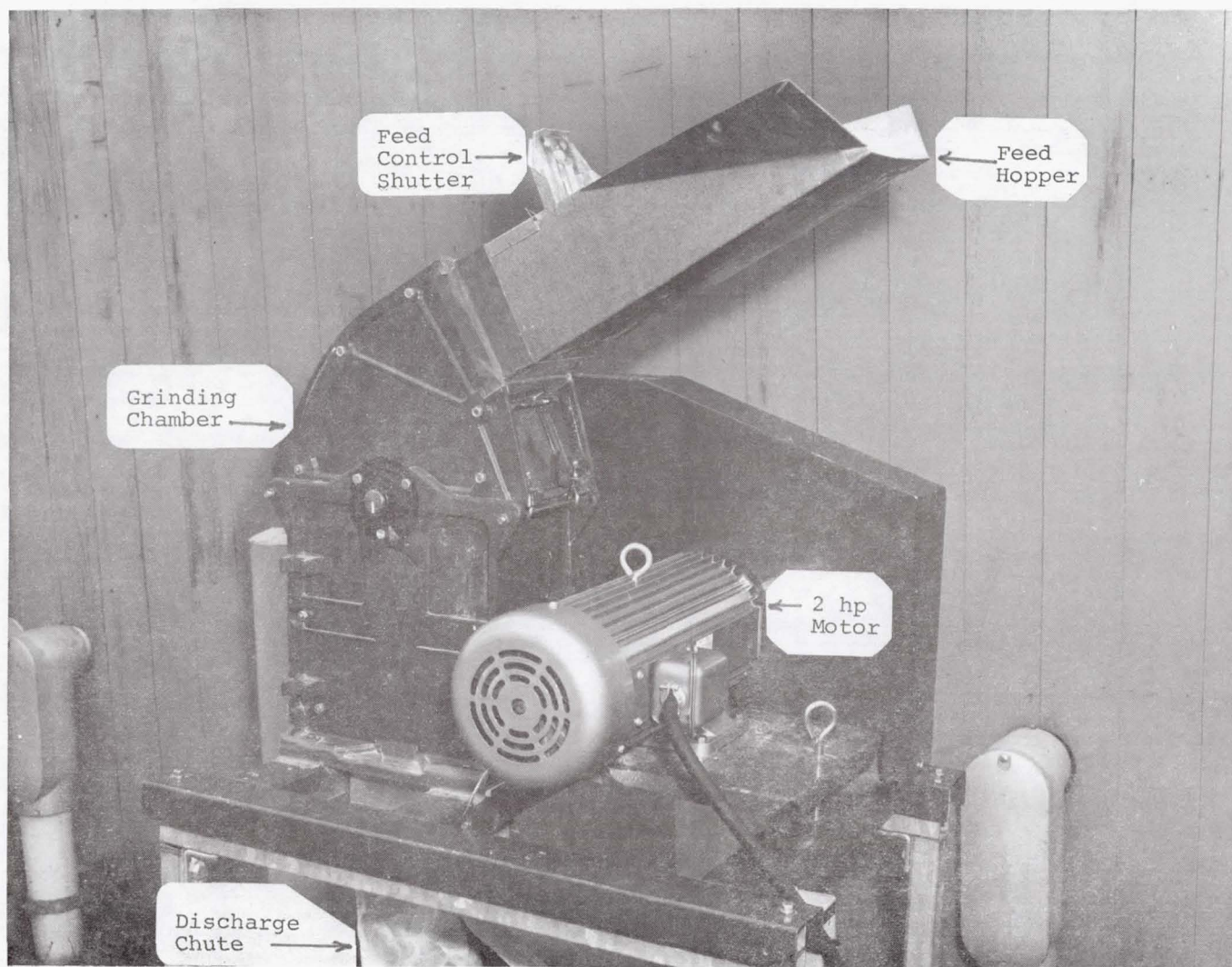
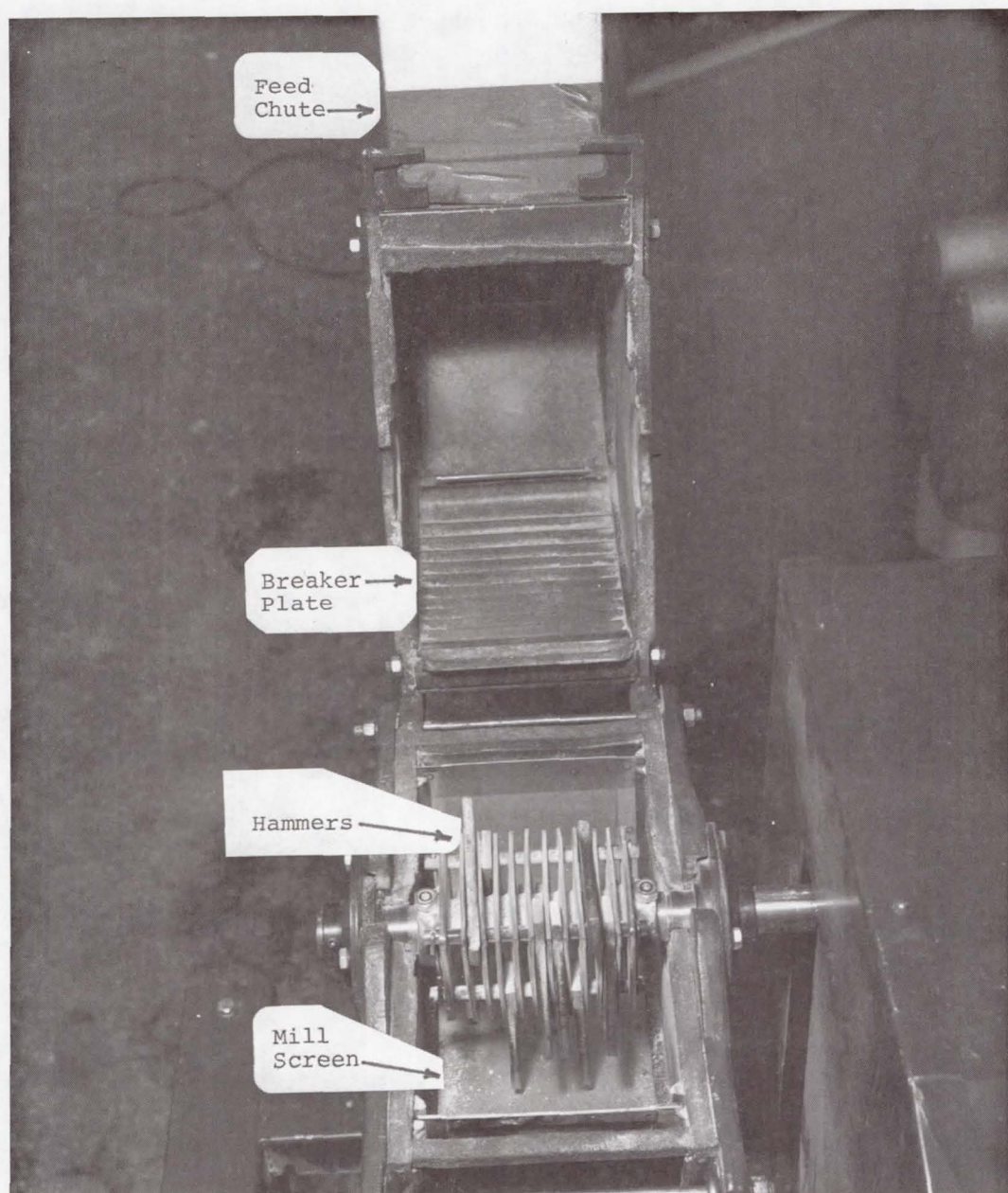


Figure 1. - C. S. Bell Comapny #10 Hammermill
Exterior View



C. S. Bell Company #10 Hammermill
Interior View

Figure 2

TEST DESCRIPTION AND PROCEDURE

Four separate tests were performed with the mill.

- 1) The effect of applied motor voltage on mill speed.
- 2) The effect of mill screen size on throughput and efficiency.
- 3) Fineness of the ground product.
- 4) Retention of grain in the mill after grinding.

In a typical PV system application, the mill would be driven by a DC motor. Hence, most of these tests were conducted using a 120 VDC motor. The manufacturer recommends a 2 to 3hp electric motor to drive the mill and LeRC applications would call for use of a 3hp DC motor. However, no 3hp 120VDC motor was available at the time of the test, so a 2hp 120VDC motor was used for most testing. Two samples of millet were ground using a 3hp AC motor to determine effect of motor-size on throughput.

The tests used locally obtained U.S. red millet, milo, wheat and corn. The mill was installed and set up according to the manufacturer's instructions. For tests using the 2hp DC motor, a 0-150VDC variable voltage DC power supply powered from an AC line was used to drive the motor.

Mill Speed - In a typical PV application using storage batteries, the voltage of a nominal 120VDC system power bus could be expected to vary from approximately 105 to 130 volts DC. Mill shaft speed vs. applied voltage to the 2hp 120VDC motor was measured for an unloaded mill using an 8" V-belt pulley on the motor and a 4" pulley on the mill. Motor voltage was increased from 100 volts until the mill limit of 4000 RPM was reached. The appropriate size motor pulley to prevent overspeeding of the mill at 130 volts applied motor voltage was then calculated and the proper sized pulley installed. A second check was made to verify that the mill speed was within limits at 130 volts applied voltage.

Throughput and Efficiency - Mill screens having 1/50", 1/32", and 1/16" diameter holes were procured with the mill. For each of the four grains, throughput and fineness of grind were determined for each screen.

To determine throughput, each screen was installed in the mill and the grain being tested was placed in the hopper. The mill was started and the feed shutter adjusted to achieve steady operation with a motor current of 14-15 amps at 120V on the 2hp motor and a mill shaft speed of approximately 3100 RPM. No current readings were available for the samples ground using the 3hp AC motor; therefore, when that motor was used, feed rate was adjusted so that the motor did not appear to be overloaded and a mill shaft speed of approximately 3500 RPM was obtained. A 30 or 60 second sample was then collected to determine grinding rate.

The effect of RPM on throughput at constant power was also measured. For this test, the 1/32" screen was installed in the mill and millet was ground. To achieve constant power, the motor power supply was set at a fixed voltage for each run and the feed rate was adjusted to obtain a current which gave 1200 watts power usage. The mill shaft RPM and throughput were then measured.

Fineness - To determine fineness of the ground product, a 0.1 kg sample of the ground product from each of the throughput tests was sieved through a series of 8 inch U.S. Standard sieve screens using Tyler equivalent screen meshes of 20, 40, 60, 70 and 100. The sieve stack containing the sample was placed on a vibrating table for 15 to 30 minutes until the flour was separated according to particle size. The percentage of total sample passing through each screen was determined by weighing. This gave a means of comparing the fineness of the resulting flours. For baseline comparison, a sample of "mixed sorgho blanc/petit mil" flour from the Tangaye, Upper Volta village chief's grinding stone, referred to as "UV gound sorgho" on the plots, was also sieved. This was the same sample used for comparison in the tests of a C. S. Bell Co. #60 burr mill(2).

Retention - Finally, grain retention in the mill following grinding was measured. This test was performed to determine the rate at which the mill emptied itself of grain after a sample had entered the mill. The results would be useful in determining the validity of possible problems resulting from loss of grain when grinding small batches and, if grain retention was significant, would help in establishing procedures to reduce these problems.

For this test, millet, milo, and corn were ground using each of the three mill screens. A sample of grain was placed in the hopper and a steady grinding rate at 120 volts and 10 amps established. As the last of the grain disappeared under the feed shutter, a timing period was begun and the mill shutdown after a period varying from 5 to 120 seconds. The amount of partially ground grain still in the mill was then weighed.

RESULTS

Hammermill/Burr Mill Comparison - The Bell #10 hammermill was found to operate with significantly less noise generation when compared to the Bell #60 Burr mill. The noise level of the hammermill is essentially independent of feed rate and fineness of grind, whereas the noise level of the burr mill is very dependent on feed rate and burr plate pressure setting, becoming almost unbearable when the mill is empty and plate pressure is high. Ear protection should be used when operating the burr mill but is not necessary when grinding cereal grains with the hammermill.

The hammermill can be operated empty with essentially no wear to the mill, but care must be taken with the burr mill to keep grain in the mill during operation to prevent excessive plate wear, especially when plate pressure is high.

Adjustment of the hammermill is easier than the burr mill, requiring only feed rate adjustment with the fineness regulated by mill screen hole-size. Feed rate slide adjustment was easier for the hammermill due to differences in feed rate shutter design. The burr mill also requires adjustment of burr plate pressure which is not easily measured or reproduced.

Mill Speed - The effect of applied motor voltage on mill shaft speed for an unloaded mill using an 8" motor pulley and 4" mill pulley are shown in figure 3. This shows that for this pulley combination, the mill speed limit of 4000 RPM would be reached at approximately 122 volts and that at the maximum expected nominal PV system voltage of 130 volts, a shaft speed of 4250 RPM

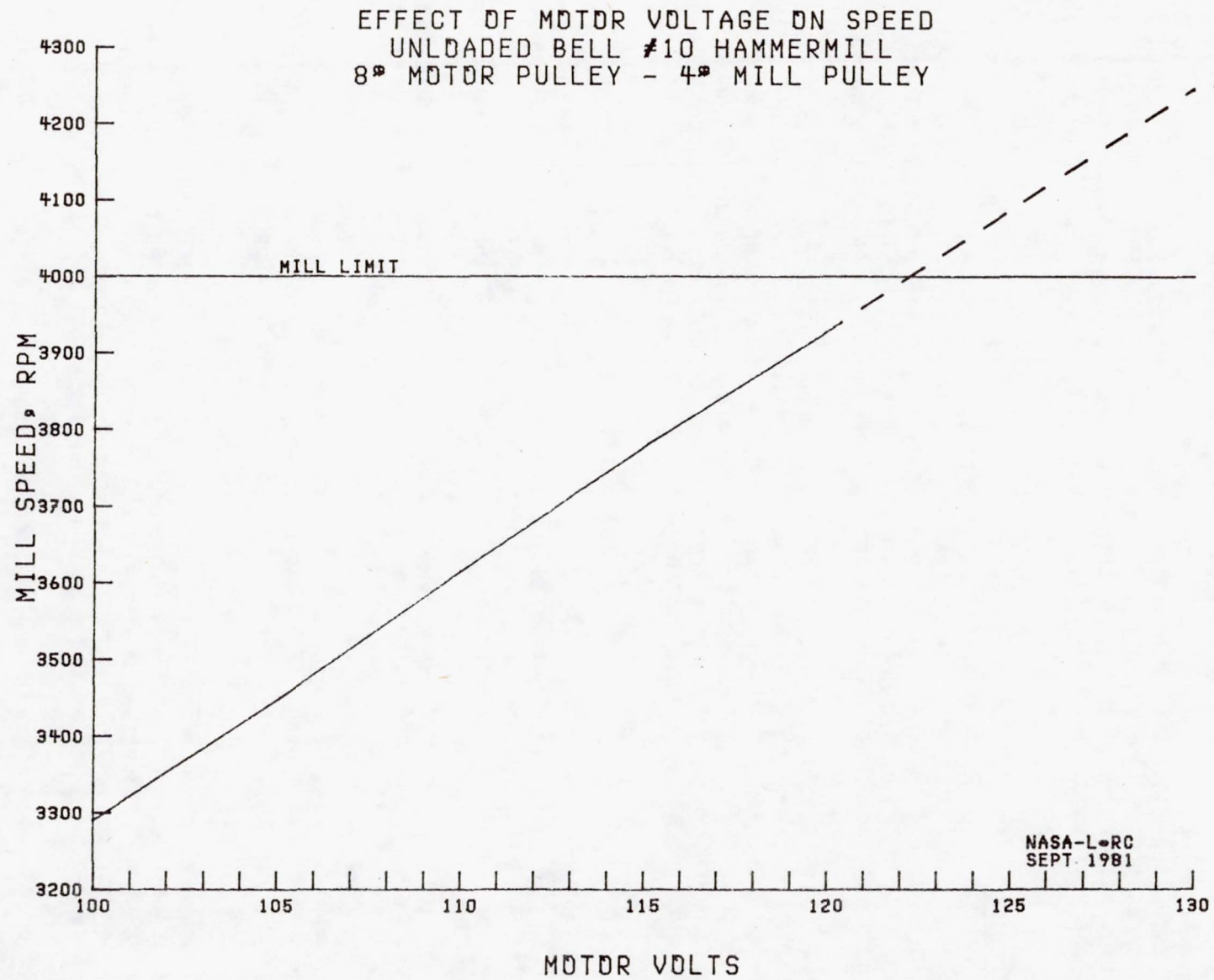


Figure 3.

could be expected. The 8" motor pulley was replaced with a 6-3/4" pulley to produce an unloaded mill shaft speed of 4000 RPM at 130 volts applied motor voltage. This modification prevents overspeeding the mill and potential mill damage and personnel injury, but causes the mill to operate at the lower end of its optimum speed range at normal system operating voltages of 115-120 volts. This results in reduced mill throughput as discussed further in the next section

Throughput Efficiency - The grinding rate and energy consumption for each grain and mill screen combination is shown in Table 1. As might be expected from the tests on the #60 Burr mill, the type of grain had a considerable effect on the grinding rate. The manufacturer's advertising brochures do not include estimated rates which could be used for comparison.

The effects of RPM on throughput at constant power are shown in figure 4. This shows that efficiency is maximized at higher RPM and indicates that the feed rate should be adjusted so that the mill does not slow down excessively during operation. It also indicates that a means of automatically regulating mill speed during operation may be desirable; i.e., regulate motor voltage to keep constant speed.

Grain Retention - The retention of grain in the mill for millet, milo, and corn for each of the three mill screens are shown in figures 5 through 7. They show that a significant amount of grain is retained in the mill, especially when the finer mill screens are used. This is especially important when small batches (under 10 kilograms) are being ground and may require extra running time or other administrative procedures to prevent customer loss of flour.

Fineness - The fineness test was performed to determine the fineness of the milled flours using the various mill screens. The tests also provided a means of comparing the milled flours with the native ground Upper Volta sorgho flour. A finer flour will pass a greater percentage of the sample through each of the Tyler Sieve screens and therefore, its curve will lie higher on the chart (Figures 8 through 11). The native ground Upper Volta sorgho flour is included in each figure for reference.

Several figures show an unexpected crossover of the curves for the same grain ground with different screens (figures 8, 9 and 11). This may be due to incomplete separation due to plugging of some of the Tyler screens. This would make a sample appear more coarse than it actually is. Time did not permit redoing these samples to verify this assumption.

For the finer flours, a tendency was noted for flour to adhere to the screens thereby complicating the measurement process. The adhering flour was of a very fine, dustlike, consistency. For the purpose of these tests, the flour adhering to the screens was included with that passing through the 100 mesh screen.

Figure 8 shows a comparison of the UV ground sorgho flour with the U.S. wheat flour. The wheat ground using both the 1/50" and 1/32" mill screens is considerably finer than the U.V. ground sorgho flour, while the wheat ground with the 1/16" mill screen is somewhat more coarse.

TABLE I
GRINDING RATES

C. S. BELL COMPANY #10 HAMMERMILL

GRAIN	MILL SCREEN SIZE	MOTOR SIZE hp	GRINDING RATE Kilograms/hr.	ENERGY USE kilograms/kilowatt-hr.
WHEAT	1/50"	2	55.3	30.7
	1/32"	2	70.2	39.1
	1/16"	2	205.2	113.6
MILLET	1/32"	2	43.1	28.0
	1/16"	2	244.4	144.9
	1/50"	3	54.5	-
	1/32"	3	86.1	-
MILO	1/50"	2	38.2	21.2
	1/32"	2	66.5	36.9
	1/16"	2	278.9	158.7
CORN	1/50"	2	31.7	18.0
	1/32"	2	44.9	25.6
	1/16"	2	156.9	86.2

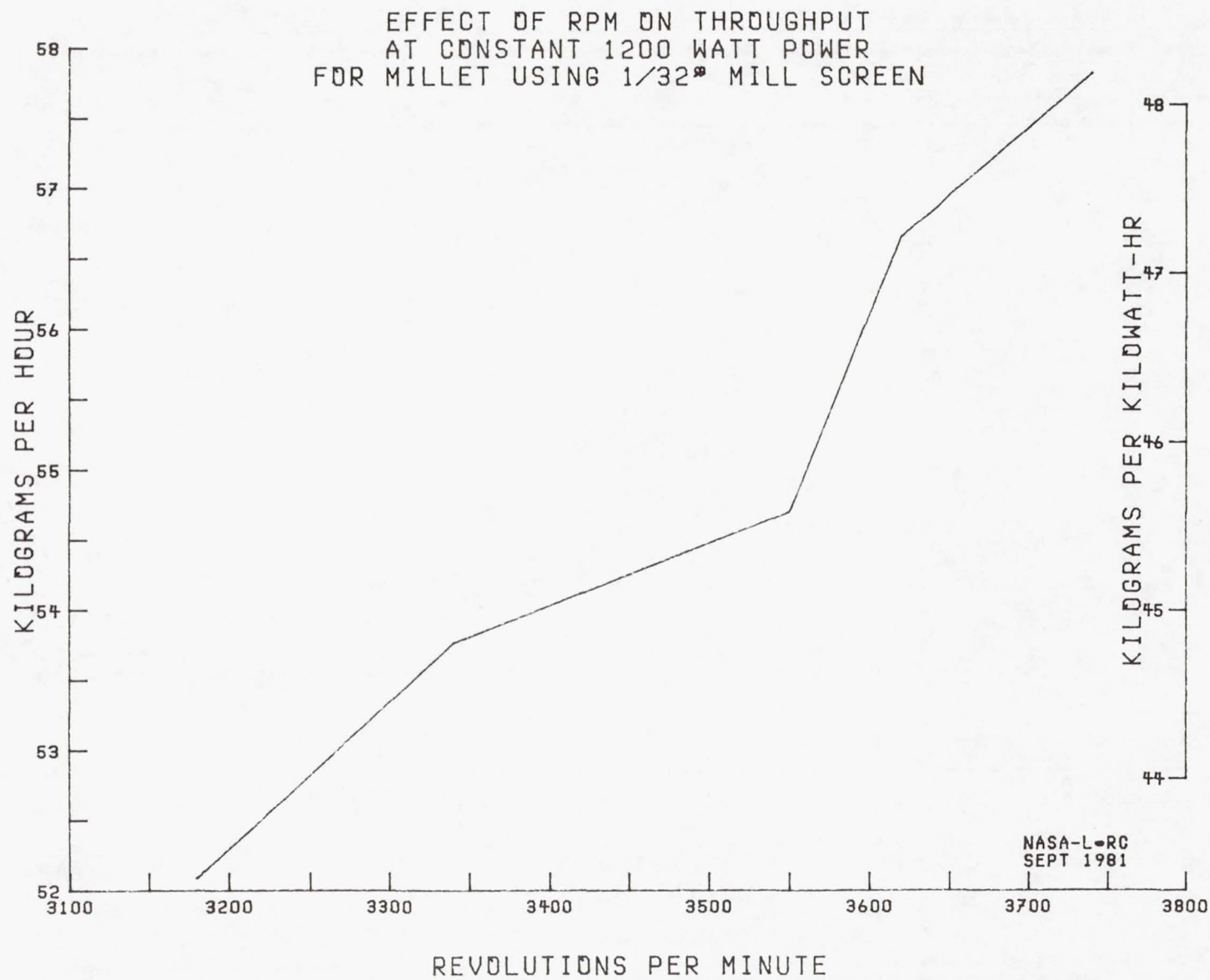


Figure 4.

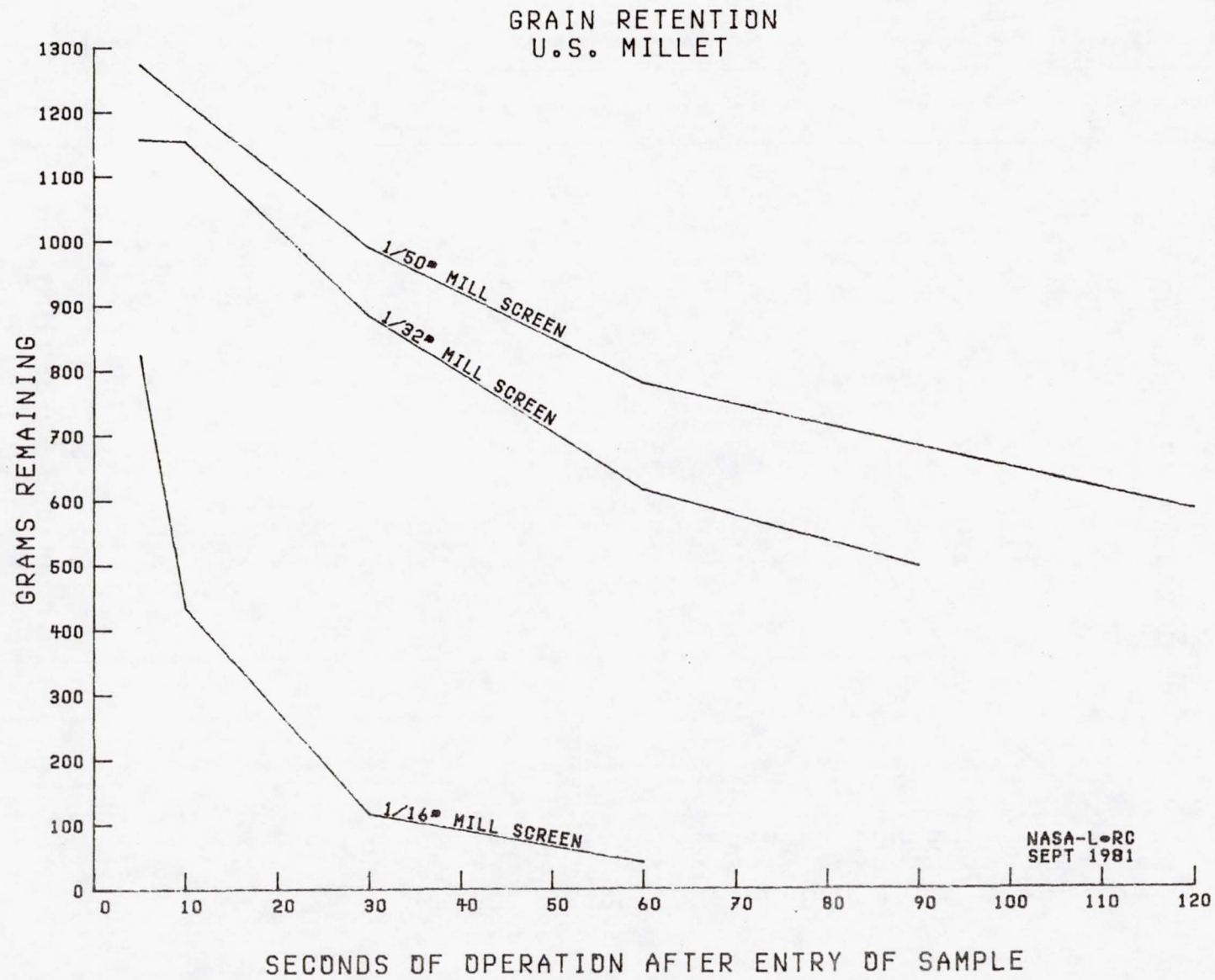


Figure 5.

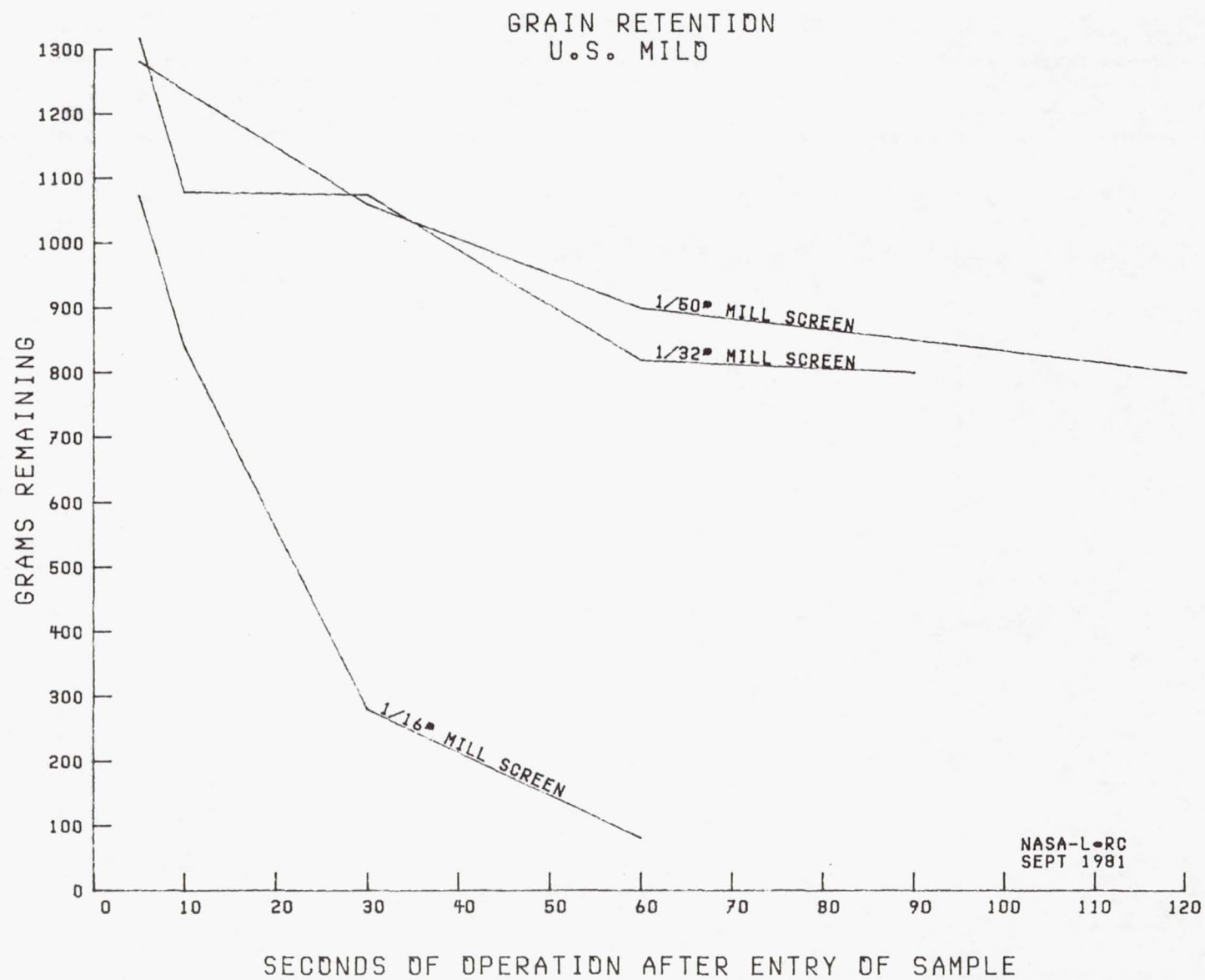


Figure 6.

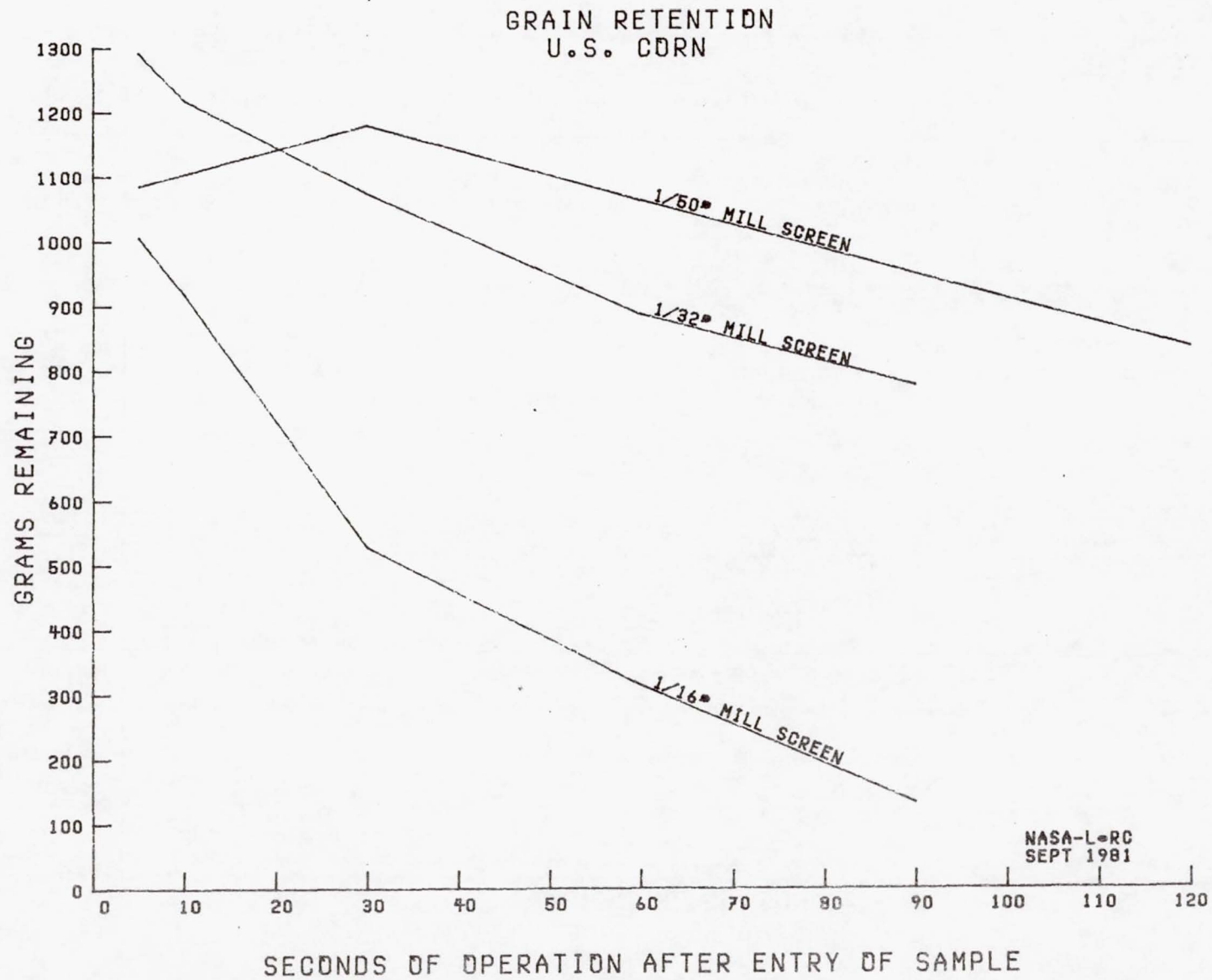


Figure 7.

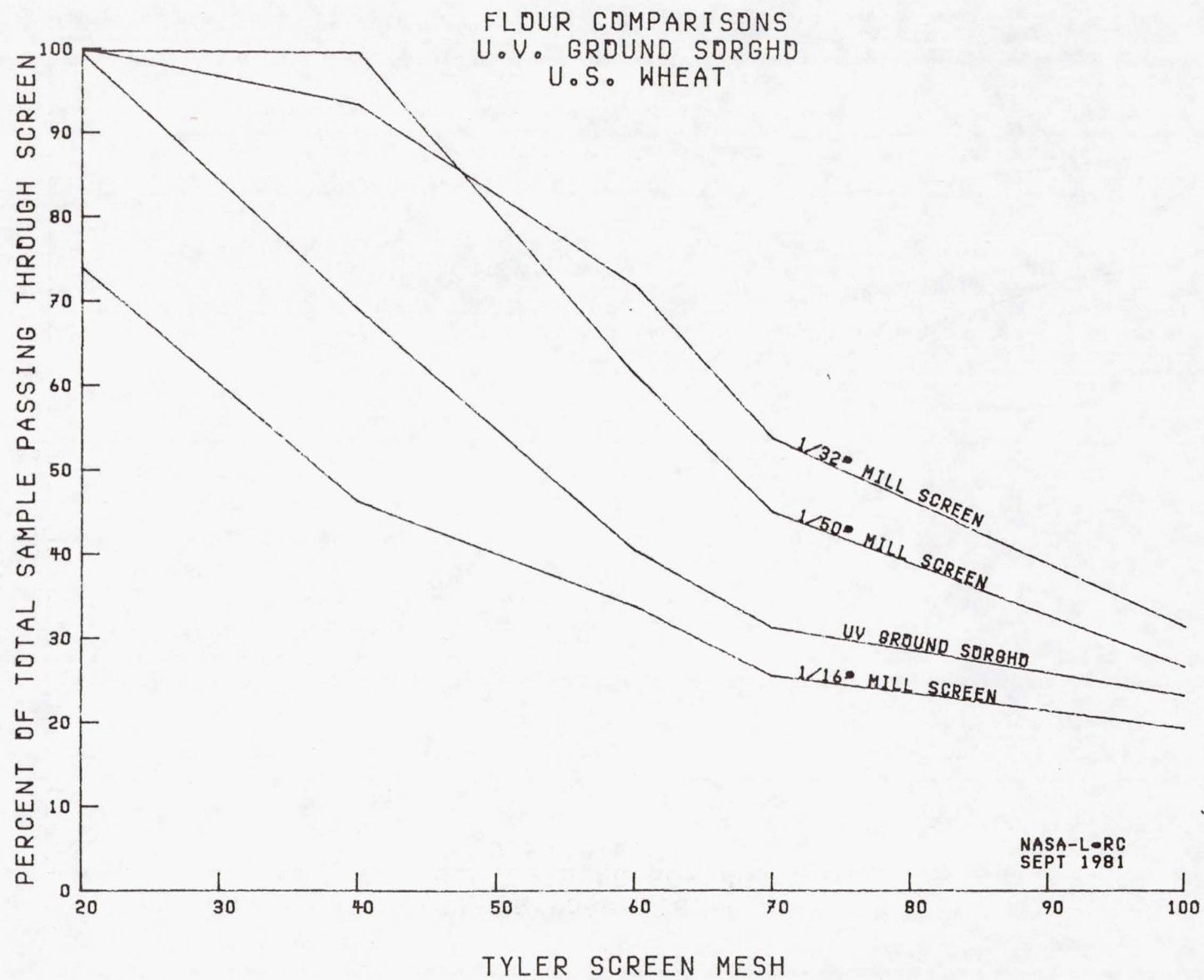


Figure 8.

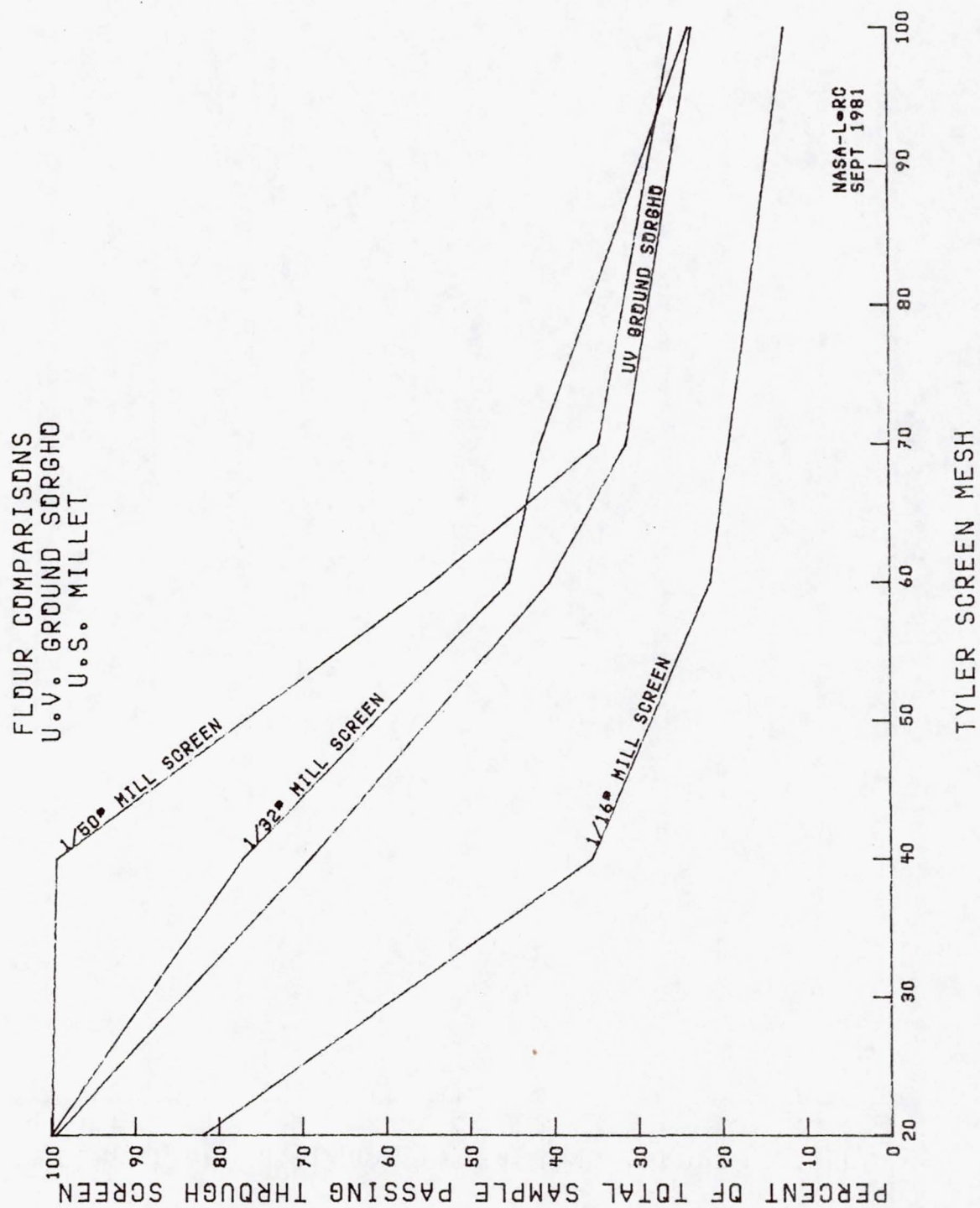


Figure 9.

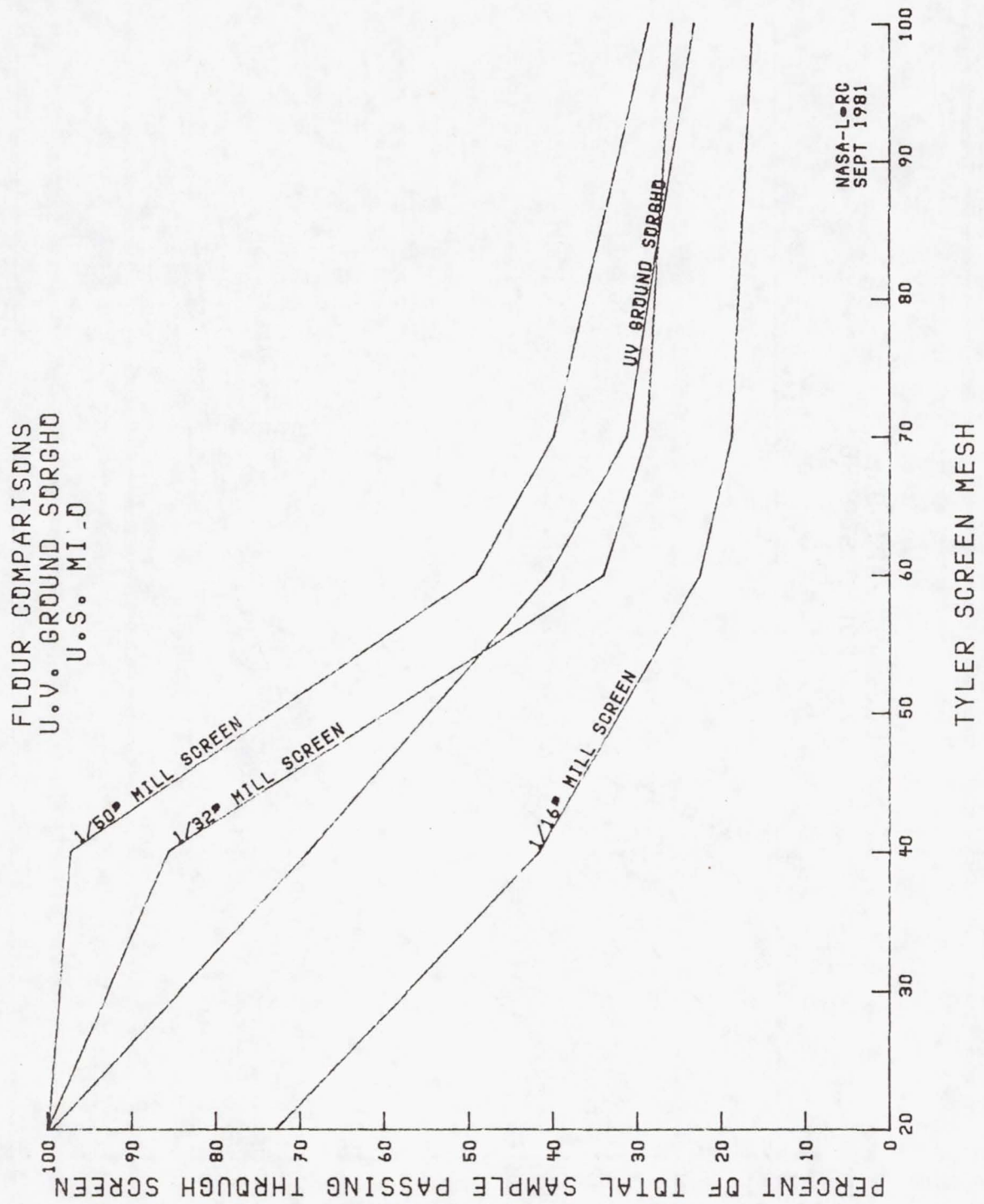


Figure 10.

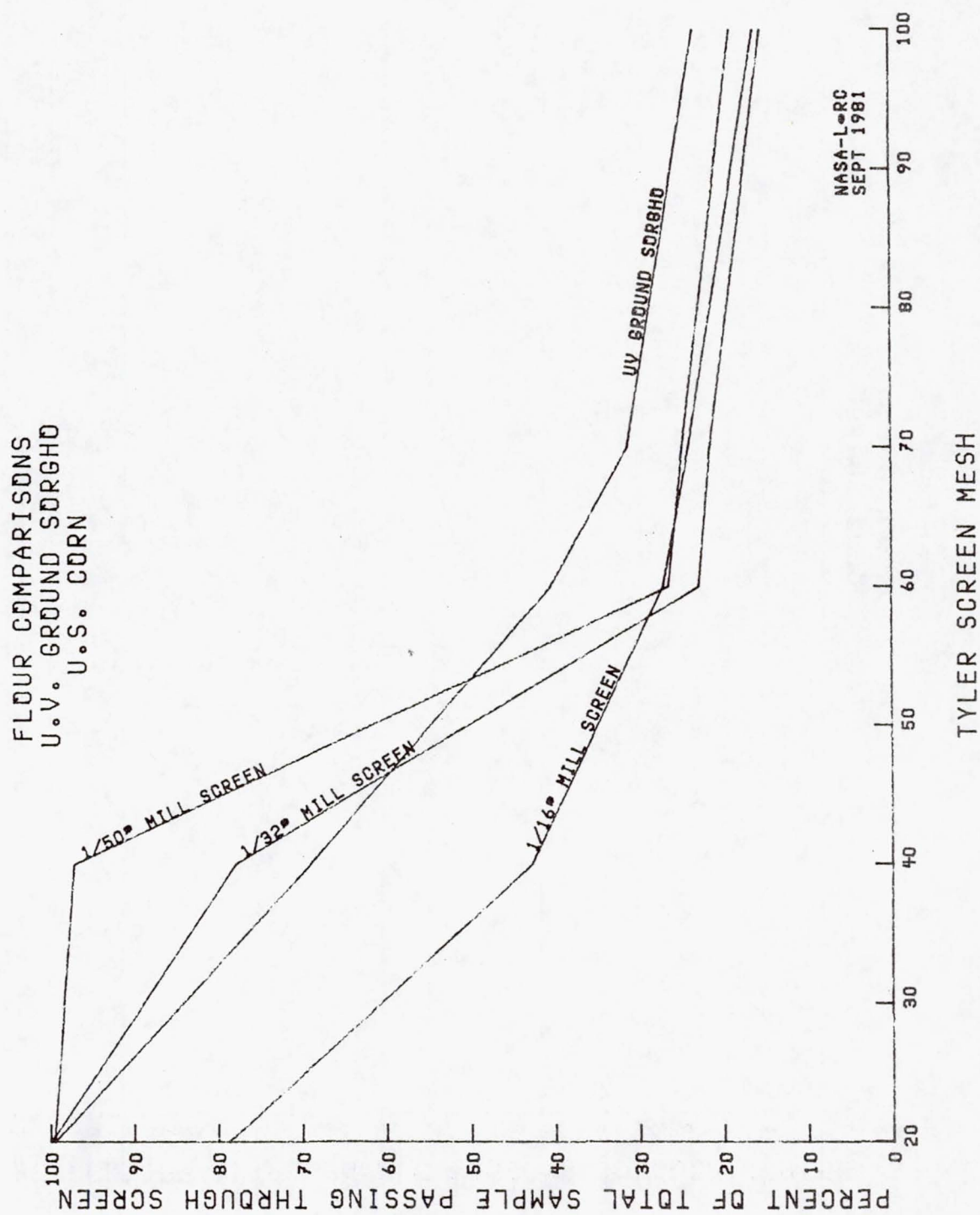


Figure 11.

Figure 9 shows a comparison of the U.V. ground sorgho flour with the U.S. millet flour. Again, the grain ground using the 1/50" and 1/32" mill screens is finer than the U.V. ground sorgho flour, while that ground using the 1/16" mill screen is more coarse.

Figure 10 shows the comparison of the U.V. ground sorgho flour with the U.S. milo flour. In this case, the grain ground with the 1/50" mill screen is finer than the U.V. ground sorgho flour, that ground with the 1/32" screen is near the same consistency and that ground with the 1/16" mill screen is more coarse.

Figure 11 shows the comparison of the U.V. ground sorgho flour with the U.S. corn flour. Here, the grain ground using the 1/50" and 1/32" mill screens are of compatible consistency with the U.V. ground sorgho flour while that ground with the 1/16" mill screen is more coarse.

It was noted that neither the size of the mill motor, nor the RPM at which the mill was run had a significant effect on the consistency of the resulting ground flour.

SUMMARY

Grinding performance tests on a C.S. Bell Co. model #10 bottom discharge hammermill indicate that the mill should be able to provide a satisfactory product at an acceptable throughput rate when grinding cereal grains for human consumption in a developing country. The tests also show that the mill is capable of grinding grain at least as fine as the Upper Volta native ground product when a 1/32" or smaller mill screen is used and that specific energy consumption is comparable to that of a Bell #60 burr mill. An additional benefit of the hammermill is that it produces acceptable flour without the necessity of prior dehulling of the grain as is generally required when using a burr mill.

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16. Abstract This report describes the first two years of operation of a stand-alone photovoltaic (PV) power system for the village of Tangaye, Upper Volta in West Africa. This was a joint project of the Agency for International Development, National Aeronautics and Space Administration Lewis Research Center, and the Government of Upper Volta. The purpose of the experiment was to demonstrate that PV systems could provide reliable electrical power for multiple-use applications in remote areas where local technical expertise is limited. The 1.8 kW (peak) power system supplies 120-V (d.c.) electrical power to operate a grain mill, a water pump, and mill building lights for the village. The system was initially sized to pump a part of the village water requirements from an existing improved well, and to meet a portion of the village grain grinding requirements. The system was designed by the Lewis Research Center and became operational on March 1, 1979. This report summarizes the data, observations, experiences, and conclusions developed during the first two years of operation. Reports of tests of the mills used in the project are included.			
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